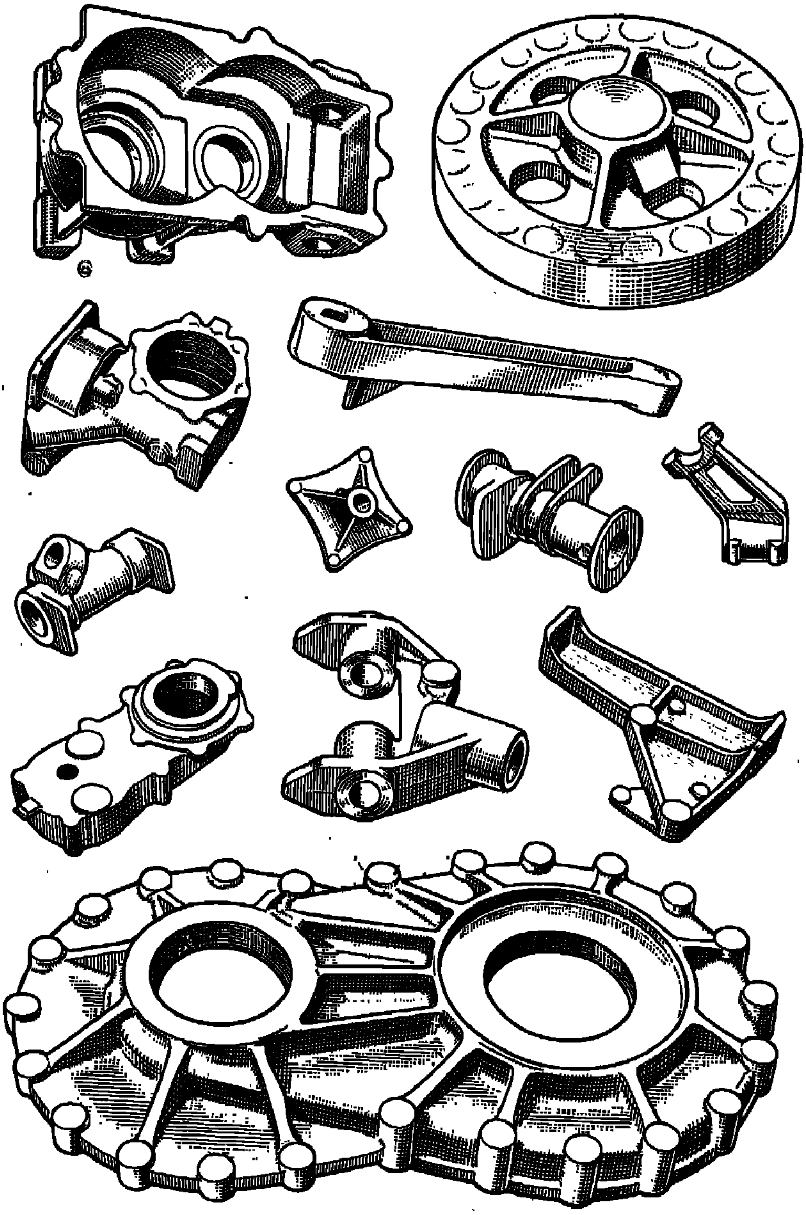
MODERN FOUNDRY PRACTICE



TYPES OF CASTINGS

In the modern mechanized foundry, castings may range in weight from under one ounce to well over one hundred tons. Although this illustration is not representative of the whole of this range, it shows the intricate nature of some of the lighter castings that are regularly in production.

MODERN FOUNDRY PRACTICE

EDITED BY

E. D. HOWARD

WITH CONTRIBUTIONS BY EIGHTEEN SPECIALIST AUTHORS

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INTRODUCTION

A SURVEY OF FOUNDRY PRACTICE

FOR more than five thousand years, craftsmen have been making metal castings for either artistic or utilitarian purposes. Specimens covering this period are housed in museums throughout the world, not with the object of portraying the development of the foundry industry but rather to illustrate such interests as the art of ancient China, the earliest types of machinery, medieval kitchenware, Roman civilization and so forth. Castings are made in innumerable alloys, but for commercial purposes they can be considered as falling into the following groups: iron (including ordinary grey iron, white iron, blackheart and whiteheart malleable) and special-purpose grey iron (including Meehanite, spheroidal-graphite and all types of alloyed iron); steel (both plain carbon and alloyed); copper-base non-ferrous metals (brass, bronze, gunmetal, etc.); light alloys (aluminium and magnesium), and miscellaneous groups such as zinc-base die-casting alloys and white metals.

For melting such a range of alloys, every conceivable type of furnace, ranging from a tiny crucible to an open-hearth tilter having a capacity of more than 100 tons, is used. The smallest commercial castings regularly made will weigh fifty to the ounce, while the heaviest in Great Britain are ingot moulds ranging between 100 and 160 tons. These large castings will require about three weeks to cool down after being poured.

The majority of castings are made in moulds compounded of green sand (that is, moist sand), dry sand, or specially-bonded (resin, sodium silicate, linseed oil) sands. The moulds are consolidated either by mechanical or hand ramming around a removable pattern, or by the skilled art of loam moulding. The terms "dry" and "green" make a distinction between moulds which later are stove-dried before filling with metal and those which are not so treated. As but few castings are solid blocks, most of the hollows are formed by the insertion of cores carrying the shape of the desired hollow. For instance, a cylindrical core forms the centre of a pipe casting. Cores are formed in much the same way as cakes, which they usually resemble in colour. A mixture of dried sand and linseed oil, starch, dextrin, synthetic resin or proprietary bond is formed to the shape desired in a corebox, then baked in an oven to form a hard transportable compact mass. Sometimes moulds or mould parts also are made of core-like material.

Not all castings are made in sand. Hundreds of thousands of tons of pipe castings are made each year by the centrifugal process in metal moulds. Similarly, of recent years many new methods of bonding sands to form moulds and cores have been developed. The ever-growing die-casting business utilizes metal moulds, and an advance on this is the mounting of metal moulds on turn-tables. These, after filling with metal, open automatically at one position, eject the casting at another, are sprayed at a third, closed at a fourth, and receive more metal at the completion of one cycle of the turn-table.

It will be realized from the foregoing that the foundry industry is both vast and complicated. Indeed, it is quite usual to find complete ignorance among foundrymen about sections of the industry not covered by direct commercial interests. For instance, a steel foundryman usually has but the sketchiest knowledge of light alloys, and vice versa. One of the purposes of this book is to present a broad yet comprehensive picture of the whole of the foundry industry. In that respect it can give to those in one section of the trade an insight into the problems and practices of the others and so help in the general appreciation of the founder's art.

FOUNDRY ORGANIZATION

A foundry is usually divided into a number of departments. A little remote, to reduce the fire hazard, are the pattern-shop and stores. The pattern-shop receives from the designer drawings of the finished casting and prepares from them wood, plaster, or metal patterns, and core boxes suitable for the manufacture of the castings. The quantity required to be made of any casting will determine the finish and permanency of the pattern. The patternmaker is also called upon to alter and repair patterns which have been damaged or become dimensionally incorrect in production. Another department is concerned with the reception, handling and storage of materials to be consumed by the melting shop, the sole function of which is to furnish at a given time, or over a stated period, a predetermined quantity of metal of the correct composition and at a proper temperature, and to do this at the lowest possible price.

The moulding department constructs the moulds either by hand or mechanically. If the latter, it usually receives its sand from an overhead supply. The sand is compounded with considerable care so as to conform to standard specifications, and quite complex machinery is used in its preparation. The cores are made in an adjacent shop, but the moulder (or his modern equivalent) sets them in position, closes and, where necessary, weights the moulds and supervises their filling with liquid metal. Metal is introduced into moulds from small basins (fashioned usually at the top of the mould) from which channels are cut (or formed) in the body of the mould material leading to the interior cavity left by the removal of the pattern. After pouring, time is allowed to permit the metal of the castings and that now filling the running system to solidify. When cool enough the casting is knocked out; that is, the mould and cores, having served their purpose, are broken away and discarded.

The castings then pass on for rough inspection before they go to the fettling shop. Here the runners (originally the channels cut in the sand between the mould and the outside for the introduction of the liquid metal) are removed. Welding, grinding, rumbling (cleaning by auto-impact in rotating barrels), shot- (not sand-) blasting and pickling are some of the many processes used for preparing castings either for the market, or for the next operation, very often in the machine shop.

Departments undertaking the heat treatment of castings are constantly expanding. Such treatment is carried out to bestow or ameliorate one or more of the properties required by the engineer, such as toughness, elasticity, rigidity, machinability, freedom from casting stresses, and so forth.

FOUNDRY CONTROL

Assisting the control of the purchase of raw materials, the whole of the manufacturing processes, the testing and even the selling, is a function of the works servicing departments, chief among which is the laboratory. Its functioning varies a good deal in the different types of foundries—sometimes it is the most important section, sometimes only a small routine checking station. Some concerns manage to do without a laboratory, but there is a growing tendency for even these nowadays to rely on independent or association laboratory services.

As many castings have to embellish the home, including baths, cooking-stoves, fire grates, washing-machines, mincers and so forth, it has been customary for a number of years to bestow upon them a durable and washable surface, often coloured, by the application of a thin layer of glass. Thus many foundries now possess a vitreous-enamelling department offering much scope for those possessing artistic and inventive talents. Similarly, in the light-alloy foundries there is often a department for the dyeing or anodizing of aluminium castings. Many castings, however, pass uncoated through many processes until, as components of a finished machine, they are dip- or spray-painted, stove-enamelled or plated.

PERSONNEL

The foundry industry employs many types of professional men and tradesmen. Among the former are accountants, engineers, metallurgists, chemists, physicists, geologists, ceramists, and welfare officers; the tradesmen include moulders, patternmakers, coremakers, fettlers, inspectors, crane-drivers, melters, annealers, and a number of other craftsmen associated with the maintenance of plant.

TYPES OF FOUNDRIES

Foundries vary from small country jobbing shops, where the owner is a practical man and will carry out himself, with but little assistance, the moulding, coremaking, melting and fettling, to huge mechanized shops where the skilled men are relegated to the equivalent of the jig and tool department. In these large shops the skill of the moulder, coremaker and patternmaker is concentrated on the production of a foolproof metal pattern to be mounted on a machine. The foundry equipment is concerned with the provision of conveyors for bringing sand to the moulding machine, cores to the moulds made thereon, and the boxes and tackle to be used by the machine moulder. There has to be provided means for taking away the cored-up moulds; the bringing up of the molten metal; the taking away of the cast-iron mould to the knock-out; the despatch of the castings to the cleaning shop; the return of the boxes and tackle to the moulding machines and the cleaning, re-preparation of the sand and its transfer to the moulding machines.

All this has to be evolved and synchronized because the manufacture of a ton of casting on the average involves the handling of over a hundred tons of material. There are several hundreds of large foundries in Great Britain where the operations are carried out more or less repetitively in mechanical fashion and these are termed mechanized foundries. Machines are now being introduced to link one mechanical operation automatically with another—this is an evolutionary change to which has been given the catchword "automation." Mechanical manufacturing methods in foundries have caused the creation of many new types of jobs, such as core-setters, inspectors, pourers, gaugers, closers, knockers-out, and so forth, allowing the operator to become highly skilled in a limited field in a short time. Improvements introduced by the operator are readily recognized and rewarded by the management, as obviously, on a repetition basis, they mean much. In a jobbing foundry it is part of the operator's duty to show such initiative, and is one of the factors which qualify him for promotion.

Working conditions are governed by agreements in existence between the employers and trade unions. In the improvement of conditions of working, tremendous strides have been made in recent years in foundries as the result of enlightened management and co-operation between employers and employed. Into this category enter the institution of washing and changing and cloakroom facilities (a legal obligation, now, in most foundries), canteens, recreational activities, first-aid and medical supervision, protective clothing and dust and fume extraction. Better lighting and heating of foundries is now the rule, and attention is being paid to clearing gangways, instituting safe-working practices and even schemes of attractive interior decoration.

Naturally, there is still quite a divergence between the largest and smallest, the most progressive and the few backward foundries, yet overall so much improvement has been registered as to bring real meaning to the motto of those largely responsible—"the foundry is a good place in which to work."

NEWER PROCESSES

During the last twenty years great developments have been made in the foundry industry. Novel though they are, they still involve the traditional techniques, and it has been the knowledgeable foundryman who has contributed most to their early success.

One of the most promising of these new processes is the shell-moulding system, invented by Cronin in Germany during the Second World War. Basically it consists in closing a box containing a mixture of sand and synthetic resin with a lid carrying on its inside face a heated pattern. The box is inverted for a short period, during which time a layer, the thickness of which depends upon length of dwell, is formed on the pattern. After a short baking, the sand layer hardens and then resembles a biscuit, which can easily be stripped from the pattern and used as one half of a mould. After assembling two such "biscuits" the mould is cast up in any of the usual casting alloys to produce a casting of closer dimensional tolerances than is obtained in normal foundry practice. This is so pronounced that machining costs are much reduced or even eliminated. So far the process has found its major use in the manufacture of small repetition castings.

Several variations of these shell-moulding or shell coremaking systems have been tried and after a period of trial have found their niche in foundry practice. One of these, for instance, is the "D" process whereby the interspace between a pattern—not necessarily of metal—and a contoured plate is filled, by means of a core-blowing machine, with a bonded-sand mixture. Afterwards this is baked and then stripped from the contoured plate. By this means a shell of variable thickness can be made from cheaper material.

Another development of recent years and one which, being more universally applicable, bids fair to overshadow all others, including shell-moulding, is the carbon dioxide (CO_2) process. This process admits of the hardening or setting of a mould or core form by gassing it with carbon dioxide. The sand from which the cores or moulds are made is compounded by adding a modicum of sodium silicate (waterglass) and the action of the

CO_2 is to convert this into a viscous material which hardens the mould or core in a matter of seconds. The process is applicable to large and small moulds and to coremaking; already a considerable degree of mechanization has been applied to its operation on a repetitive scale.

LOST-WAX PROCESS

There was a revival during the Second World War of the age-old lost-wax process, using new materials. This arose from the demand for turbine blades made from unmachinable alloys, yet which had to be of almost dimensional perfection. Because of the dearth of hand forgers the process has been greatly expanded to cover such work as the making of thousands of small components accurate as cast to thousandths of an inch. In the modern process the material placed around the wax pattern (the investment) is such that, after processing—which involves the use of very-high-temperature baking—the casting is produced repetitively to a degree of accuracy hitherto possible only by machining.

A traditional casting for the building industry is the rainwater gutter, for which a new process of manufacture is now in use. The new system involves the pouring of a definite quantity of cast iron into a metal die; while the metal is still liquid, an upper component comes down to press upon it. The gutter is thus formed in the interspace. While still hot, the gutter is transferred to a press, in which it is straightened and the flash removed.

Parallel with the development of all types of moulding machinery in foundries, including those leading to automation, there have been outstanding developments in core-blowing and in the making of hollow cores by the shell and CO_2 processes—much in demand in die-casting. Similarly, inspection facilities have been reinforced by more powerful X-ray sets, gamma-radiography, mass spectrography, and the application of ultrasonics.

Chapter 1

FERROUS METALS

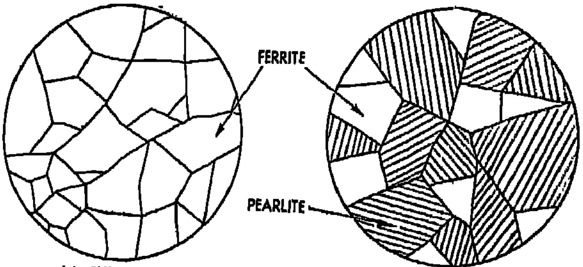
THE ferrous, or iron base, metals include the whole range of materials from pure iron up to special steels so highly alloyed that their iron content may even be less than 50 per cent. These last can hardly be recognized as related to ordinary iron or steel owing to their special properties. At the present time, we are concerned only with the more common metals in this group, and especially those which are likely to be met in ordinary foundry practice. These include cast iron in its various forms, cast steel, and various special iron or steel alloys produced in the foundry as castings. It should be explained that the more specialized and more highly alloyed iron base metals, such, for example, as the heat-resisting steels, are frequently used in the form of castings rather than as forgings or worked products, but the total tonnage of these is relatively small, and their production is so specialized that it lies outside the scope of the present work.

FERROUS METALLURGY

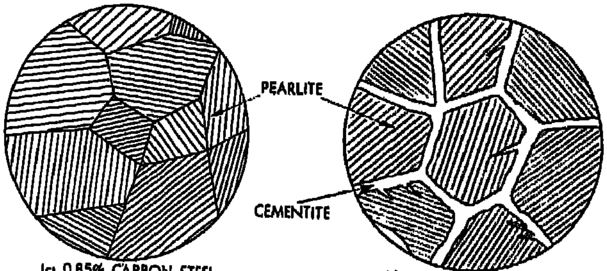
Under this heading the chief materials likely to be met in the foundry are cast iron and cast steel, and in order to obtain a clear idea of their relationship, consideration will be given to the first principles underlying their constitution. The basis of ferrous metallurgy is the fact that pure iron has a great affinity for carbon, i.e., iron readily absorbs carbon and forms a kind of alloy with it. Carbon has a profound effect on the nature and properties of the metal and, consequently, it becomes the metallurgist's job to control the quantity of carbon present in any product, as well as to control the form in which the carbon ultimately appears in the finished product.

It is necessary, therefore, to consider in the first place the effect of carbon on iron. This can, perhaps, most simply be studied by an examination of the structure of the metal as seen under the microscope. For this purpose, a series of diagrams is shown in Fig. 1.1; these will give some clue as to the nature of the product resulting from the absorption of increasing amounts of carbon into pure iron. These diagrams should be studied in connexion with the photographs of Figs. 1.2–11 and 1.18–21, which show examples of micro-structures.

Structure (a) in Figs. 1.1 and 1.2 represent a piece of pure iron under



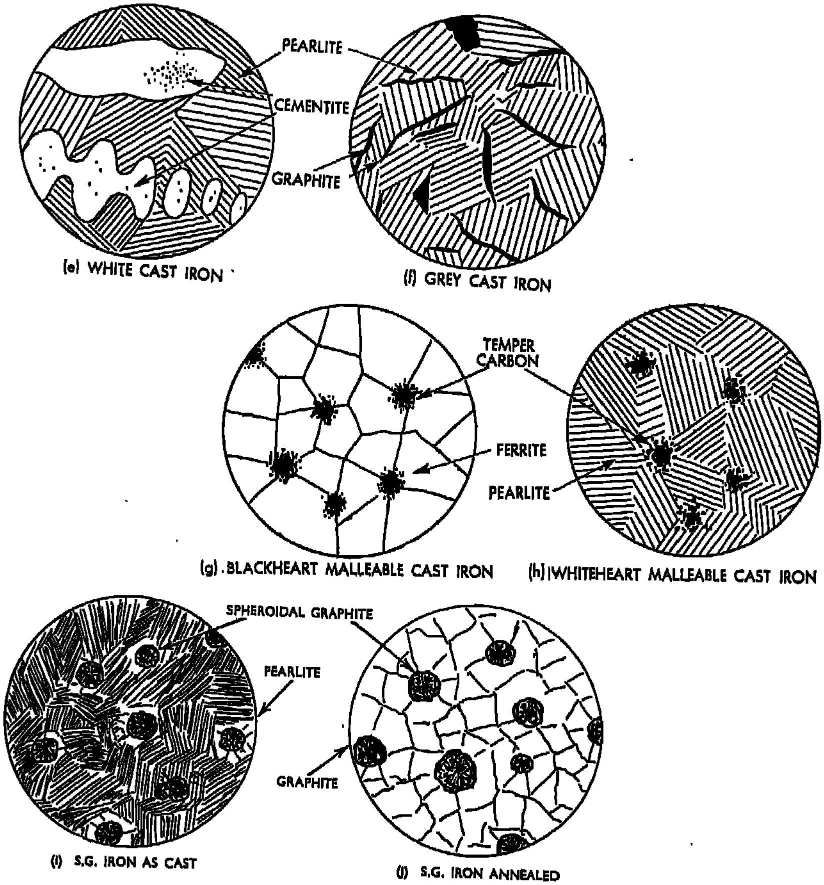
(a) PURE IRON (b) 0.4% CARBON STEEL



(c) 0.85% CARBON STEEL (d) 1.3% CARBON STEEL

FIG. 1.1. *Diagrammatic representation of the micro-structure of steel and cast iron:* (a) *pure iron,* (b) *0·4 per cent carbon steel,* (c) *0·85 per cent carbon steel,* (d) *1·3 per cent carbon steel,* (e) *white cast iron,* (f) *grey cast iron,* (g) *blackheart malleable cast iron,* (h) *whiteheart malleable cast iron,* (i) *spheroidal graphite iron as cast,* (j) *spheroidal graphite iron annealed.* (See also Figs. 1.2–11 and 18–21.)

the microscope. It consists of homogeneous crystal grains separated by thin lines. These crystal grains consist of pure iron generally termed ferrite. Structure (b) shows a piece of iron which has been converted into steel by the absorption of carbon up to about 0·4 per cent. This structure is illustrated in Fig. 1.4. It is now seen that in place of the simple grains of pure iron the micro-structure of the metal is a mixture of these grains with others which have a shaded marking. The clear part is still ferrite, but as carbon has entered the metal it has combined with the iron to form a certain proportion of iron carbide (Fe_3C). For reasons which are too technical for consideration here, this carbide appears in the final micro-structure in a laminated form rather like the edges of the leaves of a book (Fig. 1.5). Actually, the laminae consist of alternating layers of iron carbide and pure iron or ferrite. This composite structure is known as pearlite; this is on account of the pearly lustre seen on the polished and etched surfaces of pieces of iron or steel containing large proportions of this constituent.



(e) WHITE CAST IRON

(f) GREY CAST IRON

(g) BLACKHEART MALLEABLE CAST IRON

(h) WHITEHEART MALLEABLE CAST IRON

(i) S.G. IRON AS CAST

(j) S.G. IRON ANNEALED

At 0·85 per cent of carbon the structure of the metal becomes all pearlitic, as shown in Fig. 1.1 (c). Above 0·9 per cent of carbon the pearlite grains become separated and broken up by thickening bands of white material as shown in Fig. 1.1 (d) and in Fig. 1.6. It is known that this white constituent is hard and brittle. It is, in fact, a relatively massive form of iron carbide, or "cementite," which separates around the crystal grains, since the proportion of carbide is too great to be absorbed in the pearlite structure. As the carbon content increases further, so the proportion of cementite increases until, as shown in Fig. 1.1 (e), at 3·4 per cent of carbon the structure consists predominantly of large areas of these so-called massive carbides (see Fig. 1.7).

The definition of steel and cast iron must be considered here. Various

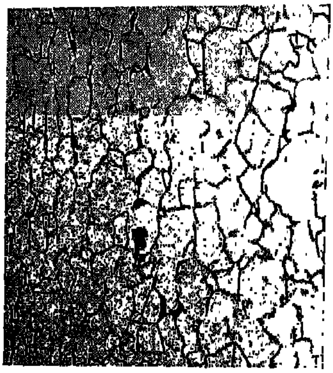


FIG. 1.2. *Pure iron × 100 diameters. Note how the crystal grains are separated by thin lines.*

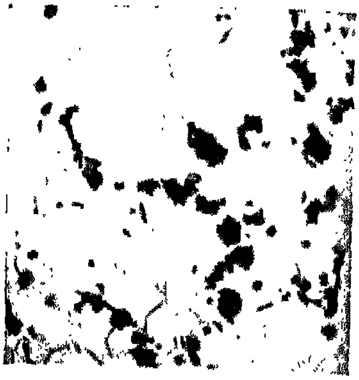


FIG. 1.3. *0·18 per cent carbon steel × 100 diameters. (C. H. Kain and T. W. Ruffle.)*

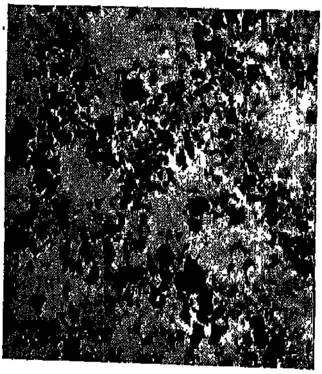


FIG. 1.4. *0·4 per cent carbon steel × 100 diameters. (C. H. Kain and T. W. Ruffle.)*

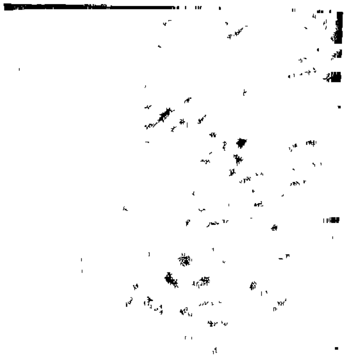


FIG. 1.5. *Pearlite × 2,000 diameters. Note the laminated form of the carbide structure.*

ways of defining cast iron in relation to steel have been attempted from time to time but, generally speaking, all definitions come back ultimately to the fact that the division between steel and cast iron is purely a question of carbon content. For certain theoretical reasons the border-line between the two is often taken at 1·7 per cent of carbon. In practice the useful metals in the two groups respectively lie in the carbon ranges well away from the 1·7 per cent border-line. Thus in steel the carbon is usually below 1·2 per cent, and in cast iron is nearly always in excess of 2·5 per cent carbon. In the intermediate range, relatively little use is made of the alloys. In Fig. 1.1, diagrams (b) to (d) all correspond to steel, while (e) shows the structure of a white cast iron.

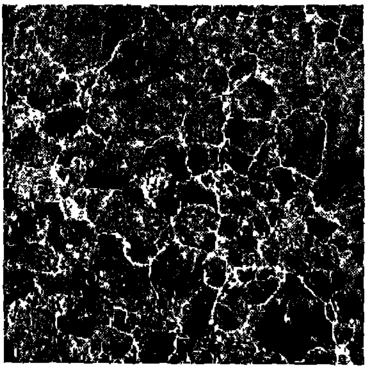


Fig. 1.6. *1·35 per cent carbon steel × 100 diameters. (C. H. Kain and T. W. Ruffle.)*

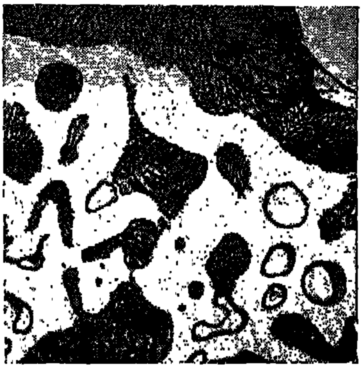


Fig. 1.7. *White cast iron (3·4 per cent carbon) × 500. The light areas are the massive carbides.*

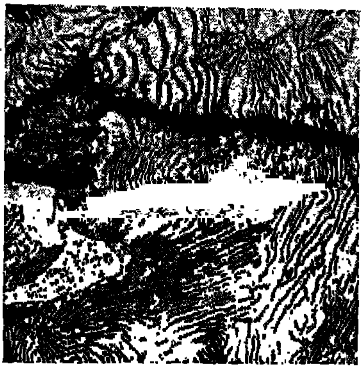


Fig. 1.8. *Grey cast iron (3·2 per cent carbon) × 500 diameters. The black streaks indicate graphite.*

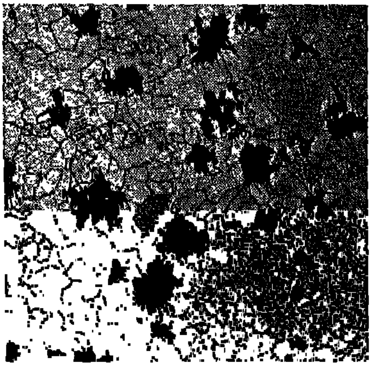


Fig. 1.9. *Blackheart malleable cast iron × 50 diameters. (Proc. I.B.F.)*

From the foundry point of view, the ranges of materials of greatest importance in these series are, firstly, that between 0·1 per cent and 0·8 per cent of carbon, and, secondly, that between 2·5 and 3·6 per cent. The first covers the various forms of mild steel and carbon steel. Below 0·1 per cent of carbon, i.e., approaching pure iron, the metal becomes very difficult to cast and handle in the foundry; and, in fact, iron with such a small percentage of carbon is only used to a limited extent in the form of castings, and even then only for special purposes.

As already indicated, alloys containing between 1·2 per cent and 2·5 per cent of carbon are of relatively little importance, although certain special compositions in this range have been developed for particular applications as, for example, in certain automobile crankshafts, which contain carbon round about 1·25 to 1·4 per cent. Over 2·5 per cent of carbon and up to the high level of 4 per cent, or sometimes 4·5 per cent, the material is cast iron.

A typical cast iron would contain 3 to 3·6 per cent of carbon. In the series illustrated it is seen that at this carbon level the metal contains a considerable proportion of the massive carbide constituent. Such a white cast iron is very hard and relatively brittle, these characteristics being derived from the carbide present. The maximum carbon ever likely to be found in a cast iron is 4 per cent, this being close to the limit of solubility of carbon in iron. The massive carbides are, however, relatively unstable when other elements are also present in the iron. Commercial cast iron contains a number of other elements besides iron and carbon; these are normally regarded as impurities being obtained direct from the ore. These other elements have a profound influence on the structure of the metal. The first and most important effect of some of them—and especially of silicon—is that in their presence the iron carbide is broken down to iron and carbon, the latter in the form of graphite flakes, thus $Fe_3C \rightleftharpoons 3Fe + C$, as shown in Fig. 1.1 (f).

It will be noted in (f) that all the massive carbides have given place to graphite (Fig. 1.8), but the carbide in the pearlite remains. The reason for this is that whilst the iron carbide in the cast iron is rendered unstable by the presence of such impurities as silicon, the carbide breaks down, as it were, in two stages, that in the massive form being much more easily decomposed than that associated with the pearlite. This is an important fundamental point since, in the bulk of engineering cast irons today, the proportion of carbon left as carbide, i.e., that proportion of carbon known as combined carbon, normally remains around about 0·45 to 0·6 per cent.

GREY CAST IRON

The relationship between the structures shown in Fig. 1.1 (e) and (f) is due to the fact that the presence of other elements or impurities in the iron has brought about the breakdown of the massive iron carbide to graphite and pure iron. The result of this reaction is grey cast iron—the usual product of the iron foundry. There are, however, other ways of bringing about this breakdown, the chief of which is by the heat treatment, or annealing, of the castings. The form of carbon structure resulting from the breaking down of the carbide by heat treatment is, however, fundamentally different from that which develops in metal where the iron is rendered grey by the presence of graphite flakes, as the normal form is called.

If a white cast iron of certain composition is subjected to a carefully

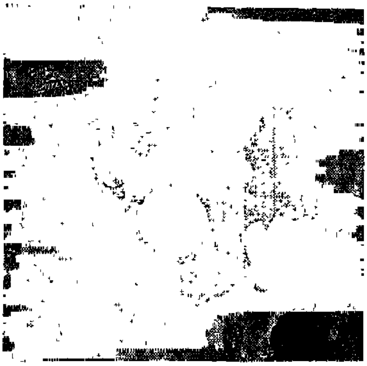


FIG. 1.10. *Spheroidal graphite cast iron as cast × 250 diameters.*

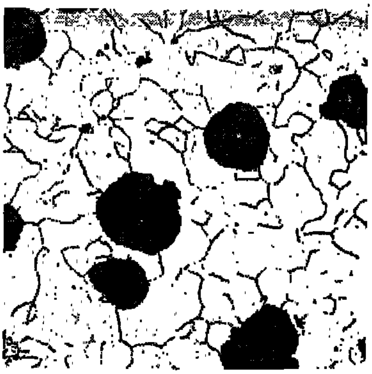


FIG. 1.11. *Spheroidal graphite cast iron annealed × 250 diameters.*

controlled heat treatment, then the structure can be broken down ultimately to pure iron and graphite, the graphite now taking the form of so-called temper carbon, as shown in Fig. 1.1 (g). The resulting material is known as malleable cast iron (Fig. 1.9).

The two methods of breaking down the carbide by control of composition and by heat treatment can be combined to varying degrees, and different types of malleable castings can be produced today. In all of these, their successful production depends upon the basic principle that all the carbon must initially be in the combined form, i.e., there must be no primary graphite in the castings before they are subjected to the malleabilizing heat treatment. The structure shown in Fig. 1.1 (g), corresponds to the metal known as "blackheart" malleable cast iron. A well-known modification of the malleable process is that producing "whiteheart" malleable iron as shown in Fig. 1.1 (h), in which the structure is not completely broken down to pure iron, but the matrix of the metal remains pearlitic (Fig. 1.18). The matrix in the case of structure (h) is the actual structure found in (e). It should be explained that in the case of "whiteheart" malleable iron an essential part of the process consists in the oxidizing of part of the carbon content out of the metal with a consequent reduction in the total carbon in the final product.

The latest development in cast iron foundry practice in recent years is the production of spheroidal graphite cast iron, generally known as S.G. iron, or nodular cast iron. (See Figs. 1.1 (i) and (j) and Figs. 1.10 and 1.11.) Castings can be made directly in the foundry with the graphite in the spheroidal form. The process developed by the British Cast Iron Research Association depends on the addition of small amounts of cerium to controlled compositions of molten iron, whilst the process developed simultaneously in the U.S.A. uses magnesium. Experience over several years has proved the magnesium process to be both more adaptable and cheaper, but sometimes it is advantageous to use a combined addition. The processes may be applied to all types of alloyed or unalloyed grey cast iron with generally a doubling of the strength and a marked increase in ductility and shock resistance. The irons may be used as cast, but preferably after either normalizing or annealing, according to the properties desired. The great advantage of these irons lies in the fact that their high carbon content ensures ready castability and their properties, approaching those of steel, can be developed in castings of all sizes and section thicknesses.

EXTRACTION OF IRON

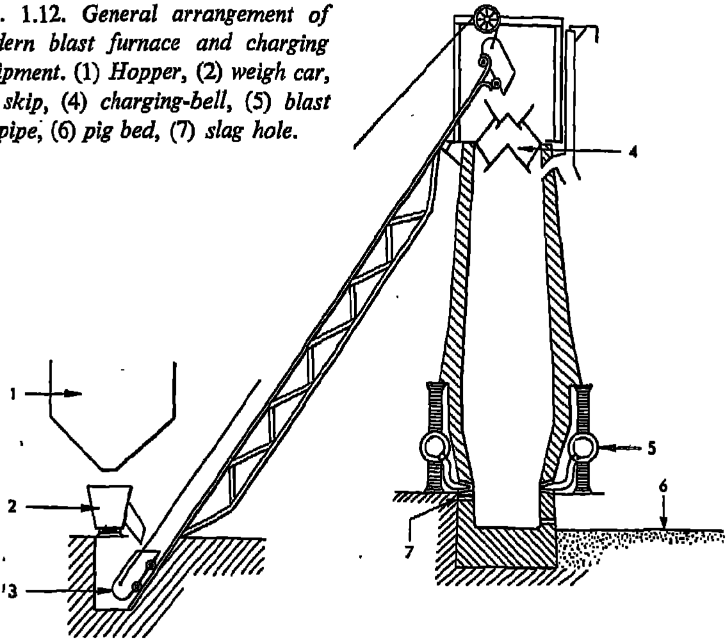
It may be of interest at this stage to refer briefly to the extraction of iron from its ores, a brief study of this being helpful when considering the metallurgy of iron in its bearing upon foundry procedure and in connexion with the basic materials which result. Iron occurs in nature in the form of various ores which are abundant in many parts of the world. As iron is the foundation of the engineering industry it is not surprising to find that industry has generally developed in the first place in centres close to adequate supplies of iron ore, provided that fuel in suitable form for its extraction is also available.

Most of the ore which is used for smelting consists of different forms of iron oxide or to a lesser extent of iron carbonate. Many of the ores are of a high degree of purity, this being in contrast with the ores of many other metals. Good iron ore contains, generally, over 20 per cent of iron, whilst specially pure ores, particularly those known as the hematites, may contain as much as 60 per cent of metallic iron. In Great Britain, most of the best quality ores are now largely worked out, and current practice depends to an ever increasing extent on imported ores. The main native ores now being worked are the relatively low grade phosphoric iron ores in the Midlands.

Many of the ores, including the carbonate ores, are sintered to burn out the carbon they contain and to leave, as nearly as possible, iron oxide free from contaminating materials. Sintering is also employed in order to assist in the recovery of dust and "fines" by aggregating the particles into more massive forms of a size and shape suitable for the extraction of the iron they contain.

The process of extracting iron from the ore, prepared, if necessary, as above, is a relatively simple one. The ore, together with hard coke, is charged at the top of a tall shaft furnace—the blast furnace—the general shape of which is shown in Fig. 1.12. Air is blown into the bottom of the

FIG. 1.12. *General arrangement of modern blast furnace and charging equipment.* (1) *Hopper,* (2) *weigh car,* (3) *skip,* (4) *charging-bell,* (5) *blast pipe,* (6) *pig bed,* (7) *slag hole.*



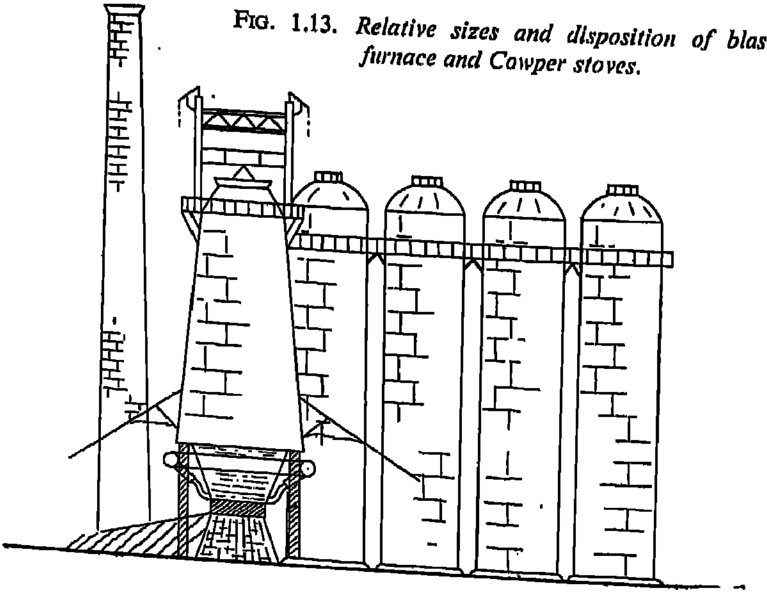
furnace, thus supplying the necessary oxygen for the combustion of the coke, and the incandescent coke brings about the reduction of the iron oxide to metallic iron, which is melted and collected in the hearth of the furnace. It should be mentioned that the ores are never free from a certain amount of earthy matter technically known as gangue, and this is taken care of by charging into the furnace also a certain amount of limestone which combines with the earthy material to give a fluid slag. The molten metal and slag are then run separately from the bottom of the furnace.

The smelting process is so simple that it was practised in the earliest days of history. The first furnaces were primitive and built of stone, and were, of course, of very low capacity. As the iron industry developed, however, these stone furnaces were replaced with larger and larger furnaces built, in the first place, from cast iron plates lined with fire-bricks, until today the blast furnace is a large erection built from steel plates lined with suitable refractories. In the early days of the development, the air blown into the bottom of the furnace was at normal temperature, and the iron produced by the furnace was known as cold blast iron.

One of the major developments in the iron and steel industry was the introduction of hot blast. It is well known that today, adjacent to every blast furnace in the country, are, generally, four tall, tower-like erections known as Cowper stoves. These stoves are packed with chequer fire-bricks, which are so arranged that the hot, incompletely burnt gases taken from the top of the blast furnace are passed through two of them, with a certain amount of extra air supply to complete combustion, thus heating up the brickwork whilst the incoming blast passes in the reverse direction through the other two stacks, thus absorbing the heat in the brickwork to provide the hot blast. After a short interval of time the blast valves are reversed and the stoves previously supplying heat to the blast are themselves re-heated by the exhaust gases, while the two freshly heated stoves now become the preheaters for the blast. Fig. 1.13. shows the relative sizes and disposition of the furnace and stoves. It will be recognized that the principle underlying the method of operation described is the usual regenerative system commonly applied to steel and other melting furnaces.

Space does not permit of any detailed discussion of the complete reactions which take place inside the blast furnace. Some idea, however, of the balance between materials supplied to the furnace and those resulting from its operation can be obtained from Figs. 1.14 and 1.15. Fig. 1.14 is self-explanatory and shows the extent to which the various ingredients of the furnace charge become rearranged during the smelting operation, whilst Fig. 1.15 shows the actual weights of materials supplied and of the products of the furnace. Fig. 1.15 is based on the quantity of materials involved in the production of 1 ton of pig iron from a typical American ore. Variations will, of course, arise in the figures shown according to the nature of the ore and the proportion of impurities it contains.

FIG. 1.13. *Relative sizes and disposition of blast furnace and Cowper stoves.*



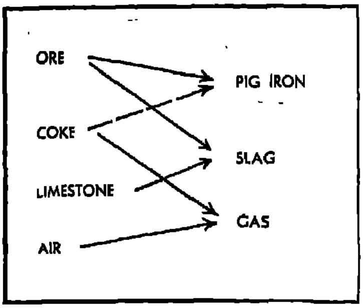


FIG. 1.14. *Relationship between the materials charged and the products of the blast furnace.*

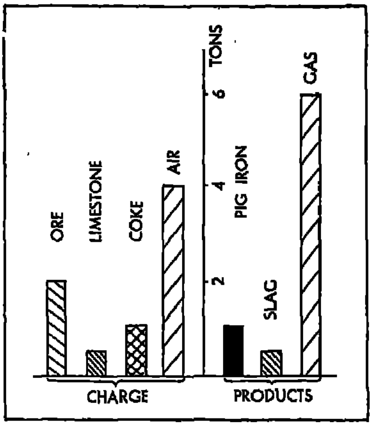


FIG. 1.15. *Relative proportions by weight of raw materials used for making one ton of pig iron.*

From the metallurgical point of view it is of interest to note that the tendency in recent years has been toward the faster and more efficient working of blast furnaces. Hot blast was the first stage in this development, while more recently bigger and bigger outputs have been obtained both by controlling the operation and by building larger furnaces, until today, many furnaces throughout the world produce from 1,000 to 2,000 tons of iron per day. While in Great Britain the average size of furnace has, in the past, been much smaller and generally less than 400 tons per day, large furnaces are now in operation in this country; for example, one in South Wales, which was started up in 1956, had an output of 1,500 tons per day, being then the largest in Europe. Several other new furnaces of comparable size are being built at the time of writing, two in Britain and others on the Continent.

This development in pig iron production has a marked bearing on the quality of the output. There seems little doubt that iron produced by the old cold blast method has certain inherent qualities not found in the modern types of hot blast iron. No satisfactory explanation of the quality of the cold blast irons has yet been forthcoming, but it is recognized today that scrap iron taken from structures built from castings made from cold blast iron fifty to a hundred years ago, is of very high quality, showing exceptional toughness and strength. For these reasons, it is customary for makers of special castings, such as rolls, to insist on a proportion of cold blast iron being included in the foundry charge. The molten metal tapped from the bottom of the blast furnace is usually cast into pigs, thus giving pig iron—the basic material handled by the iron and steel industry.

PIG IRON

The charge of molten metal collected at the bottom of the blast furnace is periodically tapped. The usual procedure is to run the metal into pig beds, these consisting of channels, moulded in a sand bed, along which the iron runs and cools. The channels are arranged in a comb-like form as indicated in Fig. 1.16. The main branch of iron taken from the sand is termed the sow, whilst the fingers of the comb each form a pig of iron weighing, normally, about 1 cwt. The pigs are broken for transport to the foundries or steelworks. Pigs cast into sand are usually somewhat rough in appearance and invariably have a proportion of sand fused on to their surface. When the pig is re-melted this sand must be removed by suitable means. For obvious reasons, therefore, attention has been given to alternative methods of preparing pigs, and the modern tendency is to run the molten metal taken from the blast furnace into a ladle, from which it is transferred to mechanical pig-casting machines. These machines consist of endless chains carrying a number of iron moulds. The metal is cast into the moulds at the bottom of an inclined slope, up which the chain continuously travels. As the moulds travel up the slope the metal is sprayed with water to assist rapid solidification. On reaching the top, the pigs are ejected and collected for transfer to the foundries. The shape of a machine-cast pig, as compared with a sand-cast pig, is shown in Fig. 1.17. In addition to being cleaner and more uniform in size and shape the machine-cast pig is usually easier to handle and, when properly designed, to stack for storage purposes.

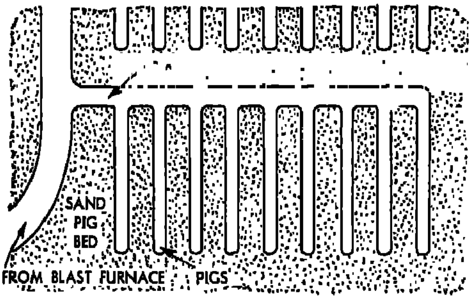


Fig. 1.16. *Sow and pigs in pig casting bed. Note the comb-like arrangement of channels.*

It should be mentioned that in addition to the above methods of casting pigs, molten metal taken from the blast furnaces is also frequently transferred direct to a metal mixer. This procedure is adopted in the production of pig iron of special composition or where the metal is being held in readiness for transfer to the steel-making furnaces. It will, of course, be obvious that being once molten a very great wastage of heat occurs

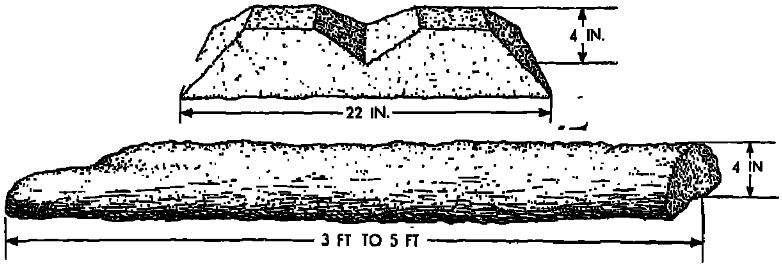


FIG. 1.17. *Machine-cast pig (upper) compared with sand-cast pig (lower).*

when the metal is allowed to solidify, and if pig iron is required immediately for steel making, the best and most economical procedure is to hold it in the molten state in a metal mixer until it is required for further treatment. Metal mixers are actually furnaces holding about 100 tons of metal, or more, which are provided with oil firing or other means of keeping the metal in a hot and fluid condition.

COMPOSITION OF PIG IRON

As already indicated, iron in the molten state has a great affinity for carbon. It is inevitable that in the reduction process in the blast furnace, where the molten iron is in intimate contact with coke and carbonaceous gases, it will absorb carbon up to the maximum possible extent. The amount of carbon absorbed in the blast furnace is dependent upon operating conditions and on the nature of the charge. It runs, generally, between 2·8 and 4 per cent. At the same time as the iron ore is being reduced, however, a certain amount of the siliceous material, invariably present with the ore, is also reduced to pure silicon. The resulting pig iron, therefore, contains silicon somewhere in the region of 0·5 up to 4 per cent. Silicon is the most important of all the elements present in cast iron in controlling structure. Low silicon gives white cast iron, and high silicon a coarse graphitic iron. This element is controlled by blending the furnace charge to produce the desired grade of pig. Manganese is also present to a greater or lesser extent in all iron ores, and quite a considerable proportion of this becomes reduced and absorbed into the iron.

In addition to these three elements, carbon, silicon and manganese, which are predominant in determining the properties of cast iron, there are also always present in pig iron other elements which are regarded more correctly as impurities. The most important of these are phosphorus and sulphur. Phosphorus occurs in many British irons in considerable quantities, and especially in those irons produced from the abundant ores mined in the Northampton and Derbyshire areas and also, to a smaller extent, in the old Cleveland ores. As these represent some of the largest supplies of ore in the country, the bulk of irons made wholly from native ore are phosphoric, and may contain up to 1 or 1·5 per cent of phosphorus. The second largest production of pig iron in Great Britain is hematite iron derived from ore deposits, mainly on the north-west and north-east coasts, as well as from imported ores. This iron is of low phosphorus type with less than 0·1 per cent of that element. It is used largely as the raw material for acid steel making, but a proportion of the output is used in the iron foundries, one of the largest applications being ingot moulds. It is interesting to note that in the U.S.A. the native pig irons are, according to British standards, low in phosphorus. American pig iron rarely contains more than 0·4 per cent of this impurity. Sulphur, picked up mainly from the coke in the blast furnace, is generally between 0·02 and 0·08 per cent in grey irons, and up to as much as 0·2 per cent in white pig iron. In addition, smaller proportions of other elements frequently occur in pig iron. These may include titanium and vanadium, and occasionally small proportions of some of the commoner alloying elements, such as chromium, nickel and copper, particularly if scrap iron or steel is included in the furnace charge.

GRADING OF PIG IRON

In the days when all pig iron was produced in the form of sand-cast pigs it was customary to sell the metal on a basis of grading by fracture. According to its analysis, and especially according to the proportions of carbon and silicon present, pig iron shows, on fracture, a corresponding amount of grey or white iron. If the fracture is grey the structure may be either fine or coarse, the graphite flakes in a coarse specimen often being ⅛ in. across. Between the finer grades of grey fracture and the white iron occur the so-called mottled irons which show mixed structures consisting of areas or spots of grey iron embedded in a white matrix. Sand-cast pigs of iron, therefore, have in the past been graded according to fracture; No. 1 being the most coarsely graphitic type of metal and No. 5 white iron. Grades 1 and 2 would be used in the production of soft common iron castings, and No. 3 for the production of better quality castings in the foundry. The mottled and white irons would be used for the production of hard castings for wear-resisting applications, for chilled iron castings, or for malleable cast irons.

Whilst most foundrymen have been familiar in the past with this system of grading by fracture, it cannot be emphasized too strongly that today, with the tendency to change to the machine-casting of pig iron, grading by fracture has largely lost its significance. This tendency for the increased use of chill-cast pigs has given impetus to the more rational method of classifying irons by means of their chemical analysis, and today, when most foundries are endeavouring to meet specifications of different types in the production of iron castings, it is being found more and more necessary to use the latter basis of grading.

Tables showing typical analysis of British pig irons produced in different districts have been published in the past. With the working out of the old ores and the increased use of imported ores in the main iron-producing districts, such tables have now largely lost their significance and from the foundry point of view the choice of supply today lies mainly between the phosphoric iron produced in the Midlands, hematite iron and the so-called refined irons. Only limited supplies of medium phosphorus iron corresponding to the older Scotch type are now available.

REFINED IRONS

Many processes have been investigated and developed from the earliest days of the iron foundry industry for eliminating some, or all, of the various impurities occurring in pig iron. An example is seen in the American washed-iron process, which consists in passing the molten iron in finely divided form through suitable slags. The impurities are burned out of the metal and a pig iron results consisting essentially of iron and carbon and substantially free from all the other elements normally found. There is today, however, an increasing demand for pig irons of controlled composition and containing, generally, proportions of carbon and silicon lower than those normally delivered direct by the blast furnaces. Such irons are required in substantial quantities for the production of modern high-duty castings made to specification. The refined irons are made by a number of methods, amongst which mention can be made of mixing blast furnace iron of suitable composition with molten steel in a metal mixer, electric furnace, or in a mixing ladle. Alternatively, blast furnace iron of suitable composition can be partially refined to steel by treatment in various types of furnaces, and with slags of types calculated to absorb the bulk of the impurities present in the metal. The carbon and silicon contents of the metal are at the same time substantially reduced.

The bulk of the so-called refined iron on the market today is, however, produced by re-melting pig iron or cast-iron scrap in the cupola, or air furnace, with proportions of steel scrap or other material so as to yield a product of controlled composition. The molten metal may be further treated in the ladle with suitable slags to give further refinement. By whatever process it is made, refined iron is today a valuable and essential raw product for use in the iron foundries in the preparation of modern high-duty iron castings. According to the process employed, refined irons can,

TABLE 1.1 ANALYSES OF FERRO-ALLOYS

	Carbon	*Silicon*	*Manganese*	*Sulphur*	*Phosphorus*	*Other Elements*
FERRO-SILICON						
Low grade	1–2	8–20	1–4	0·015–0·05	0·04–0·15	
Electric furnace	1·5	25–90	0·1–0·3	0·01–0·04	0·04–0·2	
SPEIGELEISEN	5	0·4–1	10–25	0·01	0·05	
SILICO SPEIGEL	1–2	10–15	20–25	0·01–0·03	0·015	
SILICO MANGANESE						
I	0·2–0·25	25–30	65–70		0·1–0·13	
II	0·2–0·25	21–26	50–55		0·1–0·13	
FERRO-CHROMIUM						
Blast furnace	9	1	0·4	0·05	0·05	Chromium 45–60
Electric furnace	0·5–9·0					Chromium 60–70
FERRO-MOLYBDENUM	0·3–6·5	0·05–0·2	0·2	0·02–0·05	0·01–0·03	Molybdenum 50–85
FERRO-TITANIUM						
Low grade	0·05–0·8	0·05–0·4	0·1	0·02–0·03	0·03–0·05	Titanium 10–20
High grade	0·5–3·0	0·7–1·3	0·2–0·3	0·02–0·05	0·02–0·03	Titanium 50–60
FERRO-VANADIUM	1–4	0·1–0·4	0·15–0·6	0·03	0·03	Vanadium 35–55
FERRO-TUNGSTEN	0·4–3·4	0·1–1·9	0·05	0·01–0·1	0·05	Tungsten 50–85

within reason, be supplied to any agreed specification. In addition, refined irons are frequently alloyed with such elements as copper, nickel, chromium, titanium, etc., in the refining process to yield alloyed refined irons suitable for the production of specially alloyed castings, particularly for mass-production purposes, and for most general repetition castings.

FERRO-ALLOYS

Several of the ferro-alloys used for controlling the composition of iron or steel are themselves blast furnace products. They include ferro-silicon; ferro-manganese (for adding both carbon and manganese); and ferro-chromium. The elements silicon, manganese and chromium all occur in nature in association with iron. The ferro-alloys are made by smelting their special ores directly in small blast furnaces. Some typical analyses of these are given in Table 1.1.

METALLURGY OF CAST IRON

"Cast iron" is the term used for the product of the iron foundry. It consists, basically, of pig iron remelted and cast either alone or blended with proportions of iron and steel scrap. Other chapters deal with the preparation of moulds in the foundry and describe the melting furnaces used. Here, attention will be given more to the technical side of the process of melting pig iron and other materials in the foundry and the properties of the metal in the resulting castings. In the early days of foundry practice iron castings were produced from charges of metal consisting initially entirely of pig iron, the metal, of course, being melted in the foundry cupola. However, as a certain amount of scrap accumulated in the foundry, or as scrapped castings became available, it was realized that these could be remelted as a proportion of the furnace charge.

In these early days, the selection of the furnace charge was based entirely on the visual grading of the raw materials used. Thus, if grey-iron castings were required, grey pig iron was selected, whilst for white-iron castings, white pig iron was used. In the early days it was realized that a structure intermediate between grey and white could be produced in the form of chilled iron castings. In these a grade of metal was selected which was on the border-line between white and grey in a section of pig corresponding roughly to the section thickness of the casting in question; in other words a mottled iron was chosen. Such metal after melting would be cast into moulds in which parts of the mould face consisted of iron shapes, or chills, which were inserted at those points where a hard-wearing structure was required in the metal. The resulting castings showed a white iron where the metal had been cast against these shapes, and had, therefore, been quickly cooled or chilled. The white iron skin was found to have penetrated for a depth into the casting, this depending upon the so-called chilling power of the pig and the dimensions of the chills. Beyond this white skin which, in the case of large castings, might be an inch or more in thickness, the metal was grey and relatively tough. The value of such a combination of structures can be appreciated when it is realized that the grey-iron structure is both stronger and less brittle than the white iron, whilst at the same time it can be machined, whereas the white iron, required on account of its excellent wear resistance, is unmachinable except with special equipment.

It was also realized, in the early days of foundry practice, that for thin castings it was necessary to use a coarse grey type of pig iron (Grade 1 or 2) in order to ensure that the final castings were grey. Conversely, for heavy sections of castings it was found that a No. 3 or No. 4 pig iron gave the best results, i.e., the furnace charge consisted of close or fine graphite metal. As metallurgical control developed in the foundry, it was realized to an increasing extent that the various types of iron could be blended and manipulated to give a variety of results. It was not, however, until comparatively recent times, in fact early in the present century, that any attempt was made to base the furnace charges entirely on the composition of the pig iron. This fundamental step toward scientific control in the foundry depended in the first place on the results of the work of Professor T. Turner, who first studied and explained the influence of silicon in cast iron.

As mentioned already, the normal constituents of pig iron are carbon, silicon, manganese, sulphur and phosphorus. All these elements, therefore, appear in the final iron castings, and all of them have their influence on the properties of the metal. Consequently, to obtain any given result, a careful calculation of the furnace charge is necessary in order to meet, within reasonable limits, the chemical specification which experience has indicated is required to produce the desired range of properties.

In making up the charge for the furnace in a modern foundry, other materials in addition to pig iron and iron scrap are used. Most important of these is steel scrap, which is employed generally as a dilutant of the elements normally present in the pig and iron scrap. Steel scrap had been used for some time past in this connexion, but the amounts added to the furnace charge had been generally small, probably not more than 10 per cent, or at the outside 15 per cent of the whole. Considerable attention was given during the period of the First World War to the development of steel-mix cast irons, sometimes incorrectly referred to as "semi-steel." Such irons were used on a considerable scale for munitions, perhaps one of the most striking examples being their extensive adoption by the

French for the production of shells. Since 1918 the use of steel-mix cast iron for high-quality purposes has developed gradually, and today it is common practice to employ up to 60 per cent steel in the furnace charge in many leading foundries.

In addition, great attention has been given to the production of high-duty cast irons prepared mainly on a synthetic basis. In these, striking results have been achieved by using a very high percentage of steel scrap in the charge, the amount often being between 60 and 80 per cent. Today, the use of high proportions of steel in the charge is quite common, and with the increasing use of electric melting, many foundries are making their own synthetic base iron from 100 per cent steel scrap melted with a recarburizer to raise the carbon content, and ferro-silicon and other additions, as required for the adjustment of the final composition. This gives a very pure type of iron with closely controlled composition, as required for the production of alloy and special castings.

Our present conception of the structure of cast iron is based on the realization that from the mechanical point of view cast iron can be considered as a metal having a steel-like matrix, broken up by graphite flakes in the case of grey cast iron, or by massive iron carbides in white iron. The presence of other impurities such as phosphorus also tends to introduce new constituents in the micro-structure of the metal. These also tend to break up the continuity of the matrix. Today the properties of cast iron can be calculated to a very large extent from the micro-structure, which reveals the form and extent of these various discontinuities in the metal matrix. In order to understand the ultimate connexion between composition and properties, it is necessary to look at the effect of each of the elements present in the iron.

(*a*) *Carbon.* The influence of carbon has been discussed already at some length in describing the difference between cast iron and steel. Assuming that other elements are present, rendering the metal grey, then the matrix of the metal will correspond to a high-carbon steel containing generally between 0·5 and 0·7 per cent of combined carbon. The balance of the structure consists of graphite flakes which break up the continuity of the matrix. Both the quantity and shape of these graphite flakes have a fundamental influence on the properties of the metal. This is clearly seen by the fact that without graphite flakes the matrix of the iron would, of itself, have a strength of the order of 45 to 60 tons per sq. in. In some iron castings, however, the graphite flakes are so large and break up the structure of the metal to such an extent that the strength of the resulting casting may be only some 5 to 8 tons per sq. in. A great deal of the metallurgy of cast iron today is, therefore, directed toward a study of the conditions controlling the form and quantity of graphite in the metal so as to develop the maximum possible properties in the final product. Further attention will be given to this aspect of the matter under the heading of controlling carbon, after we have considered the influence of the other elements present.

In cast iron, increasing proportions of added elements have the effect either of rendering a white iron grey or, conversely, of increasing the chilling tendency of a grey iron until it becomes white. The first type of element is known as a graphitizer and the second as a chill or carbide-forming element. Some additions have a neutral effect. Of the elements commonly found in cast iron, silicon is a graphitizer, whilst manganese and sulphur are chill-promoting elements. Phosphorus holds a more or less neutral position. The effects of the various alloys used in cast iron today will be referred to later.

(*b*) *Silicon.* As already explained, silicon is the main element in cast iron influencing the breakdown of combined carbon to the graphitic form. With no silicon present cast iron would, generally, be white in structure. As the proportion of silicon increases, however, the castings become grey, first in the thicker sections and finally, with higher silicon, in all sections of the castings. Silicon is thus the most important controlling element in iron foundry practice. Silicon is introduced into cast iron not only via the pig iron and scrap, but is also used as an addition in various forms to the molten metal to effect a final control over the structure of the ultimate product. The proportion of silicon required for any given type of casting must, however, be balanced against the amount of carbon and the other elements present, so that it is necessary to take into account the composition as a whole in making final adjustments for any given section.

(*c*) *Manganese.* Manganese is always present in cast iron, being derived mainly from the pig. Special additions of ferro-manganese are often made in the furnace in order to increase the proportion of this element where this is desired. The influence of manganese on the structure of the metal is somewhat complex since its first effect is to combine with any sulphur present forming a crystalline constituent known as manganese sulphide. Sulphur is itself a carbide-forming element or hardener, so that with a given proportion of sulphur in the iron, increases in the amount of manganese from a low value generally result in an apparent softening of the metal, due to the neutralization of a proportion of the sulphur present.

When manganese is present in sufficient quantity to neutralize all the sulphur then its true effect becomes apparent. It increases the chilling tendency of the iron by increasing the amount of combined carbon, and thus it hardens the metal. Manganese is rarely present in ordinary cast iron in excess of about 1·2 per cent. In special cases, however, larger additions

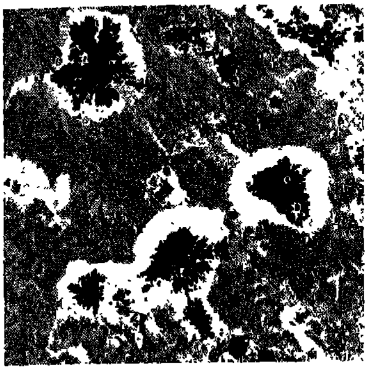


FIG. 1.18. *Whiteheart malleable cast iron × 50 diameters. (Proc. I.B.F.)*

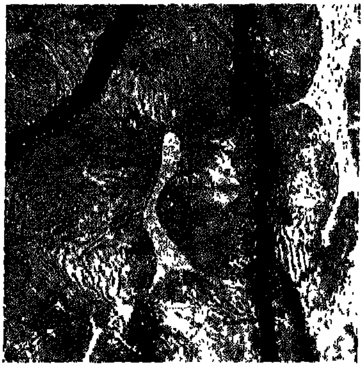


FIG. 1.19. *Phosphoric grey cast iron × 250 diameters. Note the light areas of phosphide eutectic.*

are made in the production of more highly alloyed cast irons, as referred to below.

(*d*) *Sulphur.* The effect of sulphur is closely tied up with that of manganese, as explained above. Sulphur is almost invariably present in cast iron as an impurity picked up from the fuel used in the preparation of the original pig and in re-melting in the foundry. The proportion of sulphur, normally speaking, does not exceed 0·12 per cent in grey cast iron, but the more times that the iron is melted, the greater becomes the amount of sulphur present, since sulphur tends to accumulate in the scrap. Sulphur has a powerful chilling tendency on the iron; special precautions have, therefore, to be taken for its control and removal. In grey-iron castings it should never exceed 0·15 per cent.

(*e*) *Phosphorus.* The amount of phosphorus present in iron varies very widely. In hematite iron the amount of phosphorus may be as low as 0·02 per cent. In the bulk of the ore now available in Great Britain, however, the phosphorus content runs so high that in castings made direct from native irons the phosphorus may be as much as 1·6 per cent. The existence of these high phosphorus irons in Great Britain has had a profound effect on foundry work. Phosphorus is very important in the foundry since it gives added fluidity to molten iron, and it is, therefore, particularly useful in iron used for running thin castings in which no special mechanical quality is required; for example, in many domestic and builders' castings such as rain-water pipes. From the mechanical point of view, however, its presence is often undesirable, since phosphorus introduces into the structure of the metal areas of a hard, brittle constituent known as the phosphide eutectic (Fig. 1.19). When present in considerable

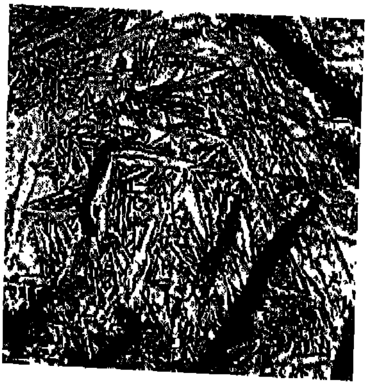


FIG. 1.20. *Martensitic grey cast iron* × *500 diameters. (Proc. I.B.F.)*

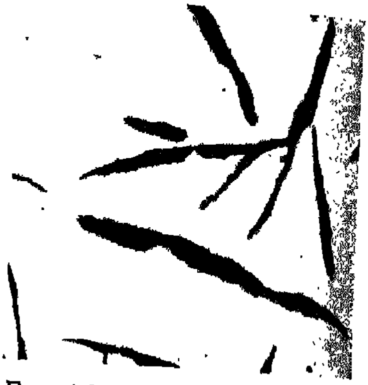


FIG. 1.21. *Austenitic grey cast iron* × *250 diameters. (Proc. I.B.F.)*

quantity in the metal, this phosphide renders it mechanically weak and destroys its resistance to shock. On the other hand it is sometimes regarded as valuable as imparting wear resistance. There is no commercial method of removing phosphorus from pig or cast iron in iron foundry practice.

In considering in greater detail the influence of these various elements on cast iron it is essential to regard them from two points of view. Firstly, on account of their influence on the foundry properties of iron, and secondly, with reference to their influence on the mechanical quality of the metal. Since all the elements present influence the character of the finished casting, it is important to have a full knowledge not only of the metal charged, but also of the changes which are likely to occur in the composition of any iron as it passes through the melting furnace.

MELTING OF CAST IRON

The bulk of the cast iron made in Great Britain is melted in the foundry cupola (see Chapter 5). The development of special types of cast iron, however, has resulted in the increasing use of other types of melting furnace, including electric furnaces. Special types include the air furnace and rotary furnace, both of which are fired either with pulverized coal or with oil, or even producer gas. In the foundry cupola the metal is intimately mixed with coke so that many of the reactions which occur during melting are similar to those taking place in the blast furnace. The changes in composition on melting may be considerable and must, therefore, be allowed for, and these can only be avoided by adopting some alternative practice in which contact with the fuel does not occur. An intermediate condition is found in rotary and air furnaces where the charge, whilst not

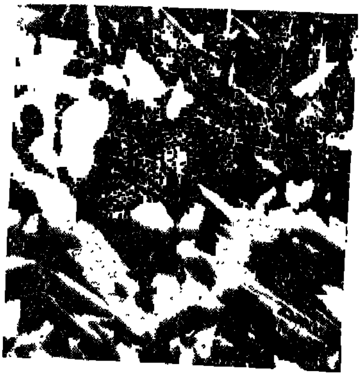


FIG. 1.22. *0·3 per cent carbon steel as cast × 100 diameters. (C. H. Kain and T. W. Ruffle.)*

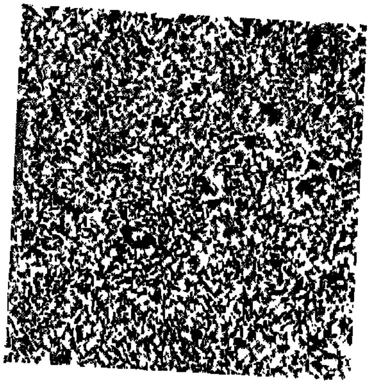


FIG. 1.23. *0·3 per cent carbon steel normalized × 100 diameters. (C. H. Kain and T. W. Ruffle.)*

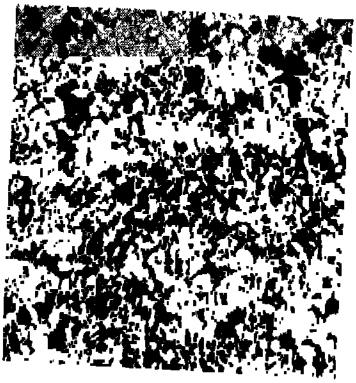


FIG. 1.24. *0·3 per cent carbon steel annealed × 100 diameters. (C. H. Kain and T. W. Ruffle.)*

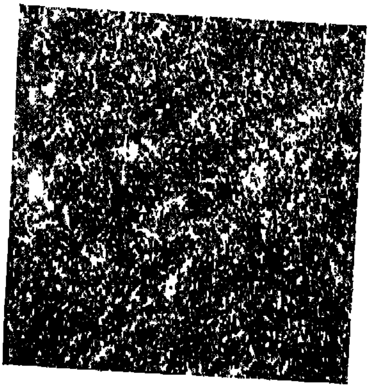


FIG. 1.25. *0·3 per cent carbon steel, quenched and tempered × 100 (C. H. Kain and T. W. Ruffle.)*

in contact with the fuel itself, is exposed to the products of combustion in the furnace.

In the foundry cupola the tendency is, generally speaking, to pick up carbon due to the intimate mixture of the melting iron with incandescent coke. This tendency, however, is counterbalanced by limitations in the solubility of carbon in iron under practical conditions, which reaches a working maximum of about 3·7 per cent. This maximum, however, is lowered by the presence of the other elements such as silicon, and in any case, as the metal approaches a composition corresponding to the solubility limit, the rate of carbon pick-up decreases. Bearing this in mind, and the fact that in normal operation the melting rate of a foundry cupola is fairly fast, it can be realized that under suitable melting conditions each cupola will tend to establish for itself a definite level of carbon content in the melt for any given mixture of metal, this level generally lying well below the limit mentioned. Carbon pick-up is, however, greater at the beginning of the blow when the furnace charge is in contact with the coke for a longer period of time and melting is slower than when the cupola is in full operation. Also at the end of the melt, when the temperature of the metal tends to rise, there may be some increase in the solubility of carbon, though pick-up may be restricted by a considerably faster melting rate.

STEEL-MIX IRONS

The extent to which carbon may be picked up in the cupola can be realized when it is recalled that a furnace charge of 100 per cent of steel can be melted as a base for cast iron. This steel may be charged with a carbon content of say 0·4 per cent, but given correct melting conditions to bring from the furnace iron sufficiently fluid for foundry purposes, it is generally found that the carbon content of the final melt will be of the order of 2·7 to 3 per cent. In the case of steel-mix irons, where the proportion of steel is, say 33 per cent, under well-controlled conditions the carbon will, generally, finish up around about 2·8 to 3·2 per cent, according to the proportion of coke and air used in the operation of the furnace, and this ultimate figure is usually independent of the amount of carbon introduced via the pig iron which forms the remainder of the charge. In the case of iron charged either as pig or scrap, the final carbon content depends both on operating conditions and the proportion of other elements in the metal. Under good working conditions, iron, for medium to heavy sections, will leave the cupola with a carbon content around 3·2 to 3·4 per cent when no steel scrap is used. On the other hand, in irons for thin section castings, as in the light foundry industry, and which are melted relatively slowly, the carbon content may be much higher—in fact, it may even go up to about 3·6 per cent.

CHANGES IN COMPOSITION DURING MELTING

Carbon tends to assist in the production of thin castings, since it gives added fluidity to the metal. High carbon also ensures longer "life" in the metal during casting. The result of this is that under working conditions metal can be cast successfully over a wider range of temperature and the molten iron can be transported considerable distances in the foundry, without becoming too sluggish for the production of sound castings. Modern high-duty irons, in which the carbon content is restricted to the range of about 3 per cent, invariably present more foundry difficulties, the "life" of the metal being short, so that higher casting temperatures have to be employed, and the metal cannot be held for any great length of time as it rapidly loses its fluidity. In the case of the spheroidal graphite irons, however, a high carbon can be tolerated since in these irons its deleterious effect on the properties is greatly reduced. High carbon assists castability, thus enhancing the value of these new irons.

With regard to silicon, this also adds fluidity to the molten iron, but the proportion of silicon aimed at must, of course, always be controlled in relation to the section of the ultimate castings. Silicon is always lost in melting, the usual loss being 10 to 15 per cent of the amount contained in the furnace charge. Due allowance must be made for this, therefore, in calculating the charge for any given ultimate analysis. As referred to below under the heading of ladle additions, the silicon loss may be made up again by means of additions of ferro-silicon, or other silicon-bearing materials after the metal has been tapped from the furnace. Such additions are particularly valuable as they not only allow flexibility of control over silicon content, but also have a special bearing on the structure of the metal. Such late additions of silicon are particularly valuable in the production of high-duty cast iron, as discussed later.

Manganese is also lost because it tends to oxidize during melting, the loss being generally 15 to 30 per cent of the amount included in the charge. Since manganese in cast iron combines with the sulphur to form manganese-sulphide, care must be taken that the proportion does not fall below that necessary to neutralize the normal sulphur content of the iron. In most high-duty cast iron, manganese is added to give a final figure between 0·6–1 per cent. The addition may be made in the furnace as ferro-manganese, or of other materials containing higher proportions of this element. Manganese adds fluidity to the iron, apart from its valuable influence in neutralizing the deleterious effects of sulphur. Less attention is usually given to manganese in common irons, where the amount may fall to as low as 0·2 per cent in the final casting.

As already mentioned, sulphur is, under most conditions, an undesirable element in cast iron. In particular, it tends to make foundry irons sluggish. It also has a powerful effect in promoting chill. Except where this is specially desired, therefore, the amount of sulphur in the furnace charge must be restricted. Sulphur is also picked up from the coke in the cupola. The degree of pick-up depends on the sulphur content of the coke and may be 20 to 50 per cent of the amount originally present. The maximum sulphur generally allowed in good-quality grey-iron castings is 0·12 per cent, a normal average figure being 0·08 to 0·1 per cent. Sulphur can be removed from molten iron to some extent by the use of additions of soda-ash. Soda-ash is a dehydrated form of ordinary washing soda

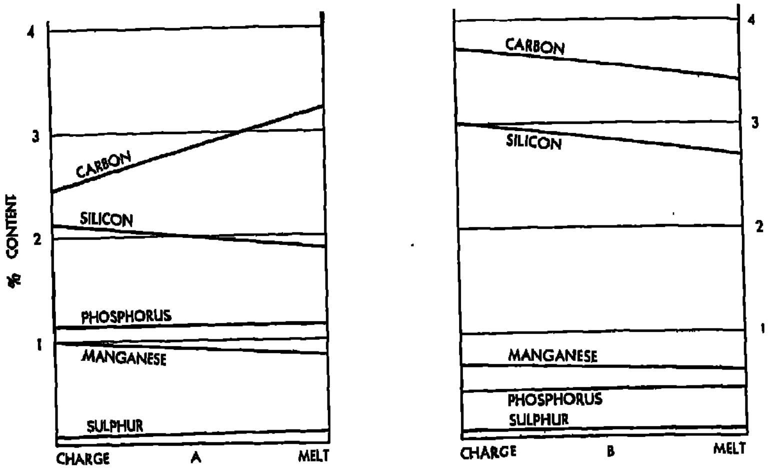


FIG. 1.26. *Changes in composition on melting typical charges in the cupola. (A) Low-carbon charge, (B) high-carbon charge.*

(sodium carbonate). The soda-ash may be charged in block form into the cupola or added as powder in the ladle. In contact with the molten iron the sodium carbonate breaks down, whilst at the same time sulphur, in an oxidized form, is absorbed and removed as a sodium sulphide slag from the metal.

Phosphorus is generally unaffected by melting conditions, so that the amount of this element included in the charge is found in the finished castings. Like other elements, however, the amount of phosphorus in the metal can be controlled within convenient limits by the proper selection of raw materials. Some idea of the changes in composition in cupola melting is given diagrammatically in Fig. 1.26.

FURNACE CHARGES

Bearing these various changes in composition in mind, furnace charges can be calculated to meet any final composition by suitably balancing in the charge various grades of pig iron, refined iron, scrap iron and steel scrap. In some foundries rooted objections are held against the use of larger proportions of steel scrap in the furnace charge. Some of these objections are justified on the grounds of excessive wear and tear of the furnace linings. Where such objections arise, a solution is available in the use of lower proportions of steel scrap, as described, and by selecting proper compositions of refined iron, for the balance of the charge; thus great flexibility of control is obtained over the metal.

In considering the calculation of furnace charges in the foundry, brief reference must be made to other types of melting. In these other types the problem of contamination of the metal charge by the fuel does not arise as it does in the case of the cupola. On the other hand, in many of these other melting units oxidization of the metal to a greater or lesser extent does occur. This is particularly so in the case of the air furnace and of the various types of rotary furnaces. The biggest problem in this connexion is frequently that of maintaining an adequate carbon content in the final metal, since whereas in the cupola a substantial carbon pick-up can always be relied upon, in the case of these other methods of melting, carbon is actually lost. It is necessary, therefore, in many cases to use as part of the charge a high-carbon iron, as for example, a high-carbon hematite, in order to achieve a reasonable level of carbon in the finished melt. Obviously, in this case also, refined irons are more useful than steel scrap for diluting impurities. Some addition of carbon can be made by means of gas coke and other forms of recarburizer added to the bath of the metal. Under the oxidizing conditions found, both silicon and manganese are also lost to some extent, but this can easily be remedied by additions of the corresponding ferro-alloys.

ELECTRIC FURNACE MELTING

Electric furnace melting is used in the production of special castings including those highly alloyed. It is used to an increasing extent in Great Britain in the iron foundry for the production of special alloy castings for crankshafts, cylinder liners and piston rings and for S.G. iron. Abroad, especially in the U.S.A. where duplexing is often practised, electric furnace melting is employed to a much larger extent than in Great Britain for a combination of metal mixing, refining and super-heating. Electric furnace melting, generally speaking, has no profound effect on the composition of the charge (unless the melting furnace is purposely controlled for refining), and very close control can therefore be achieved with comparative ease.

CONTROL OF SLAG

In all types of melting in the foundry, additions of limestone are made in the furnace charge, the object of this being to form a fluid slag with any sand and other extraneous matter that may be associated with the pig iron or scrap. The lime also forms a slag with any ash from the fuel. The slag floats on the top of the molten metal, and is removed from it in the cupola furnace, for example, by allowing it to flow from a separate tap hole at a higher level than that used for tapping the iron from the furnace hearth. A certain amount of slag, however, always passes with the molten metal into the ladles used for carrying it about the foundry, and a certain amount of slag may also be formed by the reaction of the metal with the lining of the ladle. This slag is generally removed by skimming immediately prior to casting. Reference has been made to the use of both sand-cast and machine-cast pigs. The amount of limestone which must be added in order effectively to remove the sand adhering to the former type of pig is, of course, greater than for machine-cast pig. When it is realized that, in addition, this slag has to be melted, thus absorbing additional heat from the furnace, it will be seen that the use of machine-cast pig is an all-round economy.

In the production of iron castings there are many practical details which must be observed, and which are, for the most part, a matter of experience. These include such points as casting temperature, which depends, to a large extent, on the composition of the metal, on the general dimensions of the castings to be made, and on the nature of the mould, i.e., whether in green sand, dry sand, or in chills. The effect of composition is profound in that quite heavy sectioned castings can be poured at relatively low temperatures, especially from metal high in phosphorus, and when the carbon and silicon contents also are high. On the other hand, high-duty iron, low in all these elements, requires a much higher pouring temperature.

ALLOY ADDITIONS IN THE FOUNDRY

Alloy Cast Irons now figure largely in modern foundry work, and are used extensively in the production both of high-grade grey-iron castings, and also in the many special types now available to meet particular engineering problems. Generally speaking, alloy additions can be divided into two principal groups. Firstly, additions always of a small order and never in excess of 2 per cent are made in order to improve the properties of the casting without fundamentally altering the nature of the metal. Secondly, alloy additions of a much higher order and including up to 30 per cent of the special elements are made in order to modify the nature of the metal and to produce castings with specialized properties for particular applications.

The alloy additions which can be made to cast iron are strictly limited by such factors as the cost of the addition, the fact that the alloy must combine with the iron satisfactorily and with useful results, and it must also be in a form which can readily be handled in the foundry. All the alloy additions which are used in higher proportions to produce the special types of cast iron are used also in the smaller proportions to modify the structure of the metal. As already indicated, each element present in cast iron has the effect either of increasing the amount of combined carbon present, i.e., it will tend to make the iron white in fracture, or will tend to graphitize the metal, thus rendering the iron grey and removing any tendency to chill in thin sections. In one or two cases the effects of the alloy additions lie near the border-line between these two.

Some idea of the alloy additions which are added to cast iron is given in Table 1.2, which also sets out clearly the division of these additions into chill-inducing elements and graphitizing elements. Included, also, are the elements normally found in cast iron, so that some idea may be obtained as to the probable influence of any abnormal proportions in a casting.

ALLOY ELEMENTS USED

Briefly, it may be stated that the elements normally used as alloy additions to cast iron are chromium, molybdenum, copper, nickel, and aluminium. In addition, for the production of certain special types of alloy iron higher proportions of silicon and manganese are used. Smaller proportions of some other metals, as indicated in the table, may be used as deoxidizers. These, when used, will not necessarily be found in the finished casting, as they may have done their work and been removed in the slag. These include vanadium, titanium and zirconium. In the production of ordinary low-alloy cast iron in the foundry, attention need be given only to nickel, chromium, copper, and molybdenum. It will be noted from the table that amongst these elements chromium is a carbide former, whilst copper and nickel are graphitizing elements. It is found in practice that the beneficial effects of these elements on the structure and properties of the metal may be combined in a balanced addition calculated so that the chilling power of the chromium is just neutralized by the graphitizing effect of the other addition. Generally speaking, molybdenum has no very strong influence on the amount of combined carbon in the metal.

Chromium. All these alloy additions have some influence in refining structure and improving the mechanical properties of the casting. Thus additions of chromium are beneficial in a cast iron provided that the effect of this element, in forming chill, does not result in castings which are hard and will give trouble in the machine-shop. As, however, this is a serious tendency, chromium is more often than not used in combination with graphitizing elements such as higher silicon, nickel, or copper. There are, however, other types of iron in which the chilled, or white, structure is desired, in which case chromium may be helpful in ensuring that such a structure is obtained. Chromium increases hardness and increases also the strength of the castings to some extent. It tends, however, in some circumstances, to induce a certain amount of brittleness in the metal. It stabilizes the carbides and is often useful, therefore, in castings required to resist the effects of heat.

Nickel. Nickel is, perhaps, the most useful alloy addition in the foundry

TABLE 1.2 SUMMARY OF STRUCTURAL

	Percentages used in pearlitic irons, per cent	*"Chill"*	*Effect on carbides (at high temperatures)*
Chill-inducing elements			
Chromium	0·15–1·0	Increases [1]	Strongly stabilizes
Vanadium	0·15–0·50	Increases	Strongly stabilizes
Mildly chill-inducing			
Manganese	0·30–1·25	Mildly increases	Stabilizes
Molybdenum	0·30–1·00	Mildly increases	About neutral
Mildly chill-restraining			
Copper	0·50–2·00	Mildly restrains	About neutral
Chill-restraining			
Carbon		Strongly restrains	Decreases stability
Silicon		Strongly restrains	Decreases stability
Aluminium		Strongly restrains	Decreases stability
Nickel	0·10–3·00	Restrains [2]	Mildly decreases stability
Titanium	0·05–0·10	Restrains	Decreases stability
Zirconium	0·10–0·30	Restrains	

[1] Chill-inducing effect about balances chill-restraining effect of 1½ parts of silicon, or 2½ parts of nickel.

since it refines the grain of the iron, giving increased strength whilst, at the same time, it increases the latitude of the metal by reducing the structural differences occurring normally between thick and thin sections. This is illustrated in Fig. 1.27, which shows that with nickel a greater uniformity of structure occurs than in the case of either of the chromium or straight cast irons. This effect of nickel is of great importance in that it enables castings with a high degree of hardness to be produced without the danger of machining troubles arising from chill in thin sections.

At the same time, since nickel acts as a graphitizer in a similar manner to silicon, it is found that nickel can, with advantage, replace part of the silicon content normally found. Fig. 1.27 shows four curves, each relating the hardness of a casting with section thickness. Curves A and B correspond to normal foundry cast iron. It is seen that a wide variation in hardness occurs with different section thickness in the case of iron A; the casting will be machinable in all sections, but is coarse grained, porous, and weak in the thick sections. The metal may be hardened up by reducing the amount of silicon present, when the hardness curve is as shown at B. In this case the thick sections show a desirable structure, but the thin ones are hard and unmachinable. Curves C and D show the effect of making a

EFFECTS OF ALLOYS ON CAST IRON

Effect on graphite structure	*Effect on combined carbon in pearlite*	*Effect on matrix*
Mildly refines	Increases	Refines pearlite and hardens
Refines	Increases	Refines pearlite and hardens
Mildly refines	Increases	Refines pearlite and hardens
Strongly refines	Mildly increases	Refines pearlite and strengthens
About neutral	Mildly decreases	Hardens
Coarsens	Strongly decreases	Produces ferrite and softens
Coarsens	Strongly decreases	Produces ferrite and softens
Coarsens	Strongly decreases	Produces ferrite and softens
Mildly refines	Mildly decreases and stabilizes at eutectoid	Refines pearlite and hardens
Strongly refines [3]	Decreases	Produces ferrite and softens
About neutral		Produces ferrite and softens

[2] Chill-restraining effect about one-half that of silicon.

[3] When added in small amounts and particularly when oxygen is also present.

nickel addition of about 1 per cent to each of the above irons. In curve C it is seen that the addition of the nickel to iron A results in a reduction in the hardness of the thin section and a substantial increase in the hardness of the thick sections, whilst similar effects are shown in the case of curve D. It is seen that both curves C and D lie wholly within the useful range of structure. Curve D, however, corresponds to the finest-grained and strongest iron, showing the best all-round properties.

For castings where ease

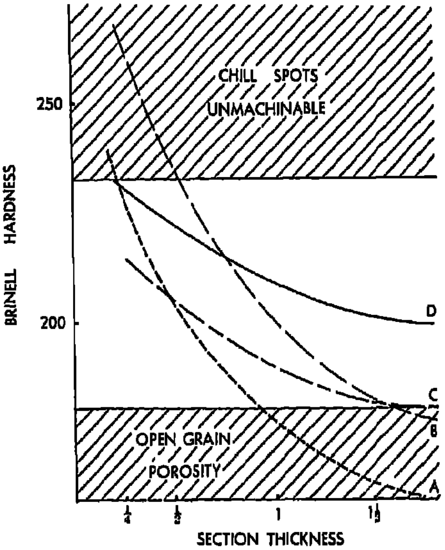


FIG. 1.27. *Hardness variation with section in ordinary and nickel cast irons.*

of machining is of the first importance, ordinary irons corresponding to curve A would have to be used under normal foundry conditions. In the case of the corresponding alloy iron, however, the metal could be hardened by lowering silicon and the increased chilling tendency adjusted with a nickel addition to obtain the best properties. This leads from curves A to B and then to D. It will be seen that the hardness of the thin sections in curves A and D is the same, but the hardness of the thick section has been increased by about 50 points on the Brinell scale. A corresponding improvement would be found in all the other mechanical properties of the metal.

Copper. A somewhat similar result can be reached by the addition of copper to cast iron. The effects of copper are, however, weaker, and the addition suffers from the serious disadvantage that it only alloys with cast iron in small proportions and its use is, therefore, restricted. The limit of solubility of copper in iron is low, and certainly less than 3 per cent, and whilst in the case of thin sections, which solidify rapidly, the castings can safely be alloyed to an extent approaching that limit. In thicker sections the amount of copper which can be added is more restricted, since, with the slower cooling conditions prevailing in such sections, a tendency for copper to separate out in the casting occurs often with disastrous results.

Molybdenum. Molybdenum is added to cast iron in proportions generally less than 1 per cent. Whilst it has no particularly marked effect on the amount of combined carbon, molybdenum is very useful in strengthening the metal. It is more often than not used in conjunction with other additions such as nickel, chromium or copper. The most interesting of these is the acicular cast irons produced by a combined addition generally of nickel and molybdenum. The microstructure corresponds to Bainite in steel and results from controlled transformation in the metal, the proportion of alloys must, therefore, be adjusted for the size and section thicknesses of the casting. A typical composition for a 1-in. section is nickel 1·0 per cent and molybdenum 1·0 per cent. The acicular structure results in high strength and improved shock resistance. It is generally used to meet Grade 26, in British Standard 1,452.

Nickel, Chromium and Copper can be added either with the furnace charge in the foundry or in some suitable form to the molten metal after it has left the furnace. In the case of nickel, the most usual form is as a nickel-silicon alloy known as "F" Nickel, which contains 92 per cent nickel and about 6 per cent of silicon. This alloy is available in the form of ingots for adding with the furnace charge or as shot for adding in the ladle. The use of "F" Nickel in the foundry is recommended since the melting point of the pure metal is well above the temperature of molten iron as handled in the foundry. The 6 per cent of silicon reduces the melting point by about 200 degrees C. There is no measurable loss of nickel in the furnace or on re-melting nickel-bearing materials. The melting point of copper, however, is well below that of molten iron and consequently copper may be added readily in the form of scrap. There is also, generally speaking, no loss on making additions of copper.

Molybdenum is added as ferro-molybdenum containing, usually, 75 per cent of molybdenum. This is generally added in the finely divided form in the ladle, or whilst the metal is being tapped from the furnace. Some loss of molybdenum generally occurs. Chromium, however, is very conveniently added in the form of alloy pig. Alternatively, ferro-chromium containing anything up to 75 per cent of chromium may be added with the furnace charge. Chromium as ferro-chromium has a relatively high melting point, so that it is not so conveniently added in the ladle. Where small additions of chromium are required in the ladle, however, a crushed form of ferro-chromium may be used, the size being controlled so as to eliminate larger particles which might not readily dissolve and to eliminate also the fine dust which would float on the surface of the metal or the slag and be lost.

ALLOYED REFINED IRON

An alternative method of making up alloy irons in the foundry is to add the special elements by means of alloyed refined pig iron, reference to which has already been made. In this case, a special refined iron is produced containing the alloy elements in the proportions required in the finished casting, due allowance being made for losses on re-melting. Alternatively, alloy refined irons may very conveniently be used as mixing irons, in which case the alloy content in the refined iron is generally of a higher order so that a proportion only of the refined iron is required in the charge for a given alloy content in the final casting. Thus, to give an example, if 1·5 per cent of nickel is required in a finished casting and the addition is to be made via alloy pig iron, then a refined iron can be purchased containing 1·5 per cent of nickel, in which case this iron must form, initially, 100 per cent of the charge. Alternatively, a pig containing 6 per cent of nickel may be used, this forming 25 per cent of the charge. The process can be carried further and refined irons are available carrying up to 10 per cent, 20 per cent, or even higher percentages of special elements; the higher the percentage the smaller, of course, is the proportion of such pig required in the charge.

Various special forms of alloy additions are also on the market. These include various types of briquettes containing alloys either as pure metals or as ferro-alloys, or even as their oxides which are mixed with

TABLE 1.3 ANALYSIS OF SOME HIGH-ALLOY CAST IRONS

	Total carbon	*Silicon*	*Manganese*	*Sulphur*	*Phosphorus*	*Nickel*	*Copper*	*Chromium*	*Remarks*
"Silal"*	2·2	5·5	0·5	0·1	0·1				Heat resistant
High silicon cast iron	1	13–16	0·25–1	0·05	0·8				Acid resisting
High chromium cast iron a	2·5–3·2	1·0	0·5	0·15	0·1			10–14	Heat resisting
High chromium cast iron b	1·5–2·5							21	Heat resisting
High chromium cast iron c	1·0–2·5	1·2–2·0						30–34	Heat resisting
"NiHard"	2·8–3·5	0·5–1·0	0·6–1·2	0·12	0·4	4·5		1·5	Wear resisting
"NiResist"	3·0	1·5	1·2	0·12	0·2	14	6	2–4	Corrosion and heat resisting non-magnetic
"Nicrosilal"*	1·7	4·5	0·8	0·10	0·2	18		2	Heat and corrosion resisting
"Nomag"*	3·0	1·5	7·0			11			Non-magnetic
Low expansion cast iron	2·2	1·5	0·8			34–36		2	Minimum thermal expansion

*Registered Trade Mark

aluminium powder so as to induce a "Thermit" reaction when the briquette is heated in contact with the molten charge. This reaction takes the form of an almost instantaneous oxidation of the aluminium and a reduction of the metallic oxides to metal, in which state they are rapidly absorbed.

HIGH ALLOY CAST IRONS

As indicated above, types of alloy cast irons have been developed in recent years in which special properties can be obtained by the use of higher proportions of the elements normally occurring, or used as alloys. A brief note of some of these more special types of irons follows, whilst Table 1.3 gives some typical compositions.

(1) *High Silicon Cast Irons.* Cast irons containing high proportions of silicon, generally in the range of 5 to 7 per cent, are used on account of their special heat-resisting properties. These irons were initially developed by the British Cast Iron Research Association under the trade name of "Silal." In addition to their oxidation resistance, these irons are relatively strong at high temperatures but compared with ordinary grey iron they are brittle under more ordinary conditions. They have proved very useful for certain types of furnace casting. Cast iron alloyed with 12 to 14 per cent of silicon has been used for some time past for acid-resisting castings under such names as "Tantiron," "Duriron," and "Ironac." This alloyed iron is white in fracture and is unusually hard and brittle. Castings can in no circumstances be machined, and they are so weak that they fracture like glass when dropped on the floor. These irons are, however, important since they provide a remarkable degree of resistance to attack by strong mineral acids for which very few materials are satisfactory.

(2) *Higher Manganese Cast Irons.* Cast irons alloyed with high proportions of manganese, generally up to 3 per cent, are used where special structures are required as, for example, in certain types of crushing rolls. Manganese is a carbide-forming element, and the castings, therefore, tend to become white. If, however, this chill-forming tendency is suppressed in heavy sections, then castings with a hard matrix result, showing a high degree of wear resistance. They are particularly useful where a coarse, hard structure is needed for certain crushing applications. With greater additions of manganese the castings tend to become white and unworkable, but such additions are of interest when used in conjunction with other elements such as nickel. These will be referred to below.

(3) *High Chromium Cast Iron.* Chromium cast irons are white, due to the carbide-forming tendency of this element. These irons are important, however, on account of their heat resistance. Irons containing up to about 30 per cent of chromium are produced regularly and have, in addition to a high degree of heat resistance, strength at high temperatures, good wear-

resisting properties and certain corrosion-resisting properties which make them of special value. These irons generally contain low total carbon, even down to 1 per cent, and, on this account, show all round good mechanical properties with machinability. They require, however, special foundry technique in their production.

(4) *High Nickel Cast Iron.* Cast irons containing higher proportions of nickel provide a series with widely varying properties. Castings containing over 2 per cent of nickel tend to be hard. These castings correspond to the air-hardening and heat-treatable irons which will be referred to later. At 4·5 per cent of nickel, cast iron is martensitic (Fig. 1.20). This structure is associated with excellent wear resistance. If the castings are white or chilled, the iron is known as "NiHard" and is used for crushing and grinding parts, for chilled rolls and for sand handling equipment. Above 18 per cent of nickel the castings are relatively soft and show a high degree of resistance to heat and corrosion. It is found also that the castings in this series are non-magnetic. Irons in this range are, in fact, austenitic in structure (Fig. 1.21), and owe many of their valuable properties to this fact.

Nickel is rarely used alone in the production of these austenitic irons. Copper can replace some of the nickel and thus the well-known special iron "NiResist" was developed. The composition of this iron is 14 per cent nickel, 7 per cent copper, and 2 per cent of chromium. As mentioned above, manganese can be added with nickel in higher proportions, and the well-known non-magnetic cast iron "Nomag," containing 10 per cent of nickel with 6 per cent manganese, is in this class. This iron is again austenitic. Another austenitic cast iron is "Nicrosilal," which combines the austenite forming tendency of nickel together with the special heat-resisting qualities of the "Silal" type of high silicon cast iron. "Nicrosilal" usually contains about 18 per cent of nickel with 4·5 per cent of silicon, the composition otherwise being as shown in Table 1.3.

Other types of high nickel cast irons are of special interest on account of their unusual properties. Reference has already been made to the use of nickel in producing corrosion-resisting, heat-resisting, and non-magnetic castings. Another special class is that of the low expansion cast irons. The co-efficient of thermal expansion of grey cast iron is about eleven millionths per degree centigrade. The austenitic cast irons, however, have a high expansion, the co-efficient being around about eighteen millionths. A peculiar characteristic of high nickel irons containing round about 34 to 37 per cent of nickel is that they show an abnormally low expansion, this being down to about five or six millionths. This is a special property of value in certain particular classes of work, as, for example, in measuring gauges subject to fluctuating temperatures.

(5) *Aluminium.* Little reference has been made to the use of aluminium as an alloy addition to cast iron. The reason for this is that whilst aluminium alloys readily with iron, the resulting material is difficult to cast owing to the tendency of the aluminium to oxidize in the molten metal, giving dirty castings carrying heavy accumulations of alumina. Reference must, however, be made to certain special types of high aluminium heat-resisting cast irons as, for example, "Cralfer," which is a form of cast iron (also developed by the British Cast Iron Research Association) containing higher proportions of aluminium and chromium, and cast under special conditions to eliminate the oxidation difficulty.

As stated earlier, the new S.G. iron process can be applied to all types of grey cast iron replacing the graphite in the flake form with spheroidal graphite. This is of special interest in providing a means of improving the properties of some of the high-alloy cast irons. The corrosion and heat resisting alloy iron, "Ni-Resist," is a good example. In the normal form, this iron is relatively weak, but in the S.G. form, its strength will approach 30 tons per sq. in., with an elongation often of 25 per cent. Such an iron becomes of great interest as a substitute for stainless-steel castings in some applications.

STRENGTH CHARACTERISTICS

A considerable amount of attention has been given in recent years to the development of iron castings with strength characteristics substantially better than those normally associated with cast iron as produced under ordinary foundry conditions. As already stated, cast iron can be regarded as a high-carbon steel in which the matrix is broken up by the graphite flakes and other inclusions and, as a result, the strength of the casting is reduced to a relatively low level. The development of irons of specially high strength depends in the first place, therefore, on the control of the quantity and form of the flakes or inclusions tending to break up the continuity of the metal. Obviously, one of the first ways of effecting this is to reduce the amount of the interfering elements and thus to render the metal more homogeneous. The main directions in which attempts have been made to improve the strength and other properties of iron castings have been, firstly, by reducing the quantity and size of the graphite flakes and, secondly, by employing metal mixtures low in phosphorus. The use of steel scrap in the furnace charge as a dilutant in the pig is one of the more obvious directions in which these may be effected.

Other courses open to the foundryman include the efficient control of the cupola furnace so as to ensure minimum pick-up of carbon in melting. Perhaps of greater importance, however, is the control over the form and size of the graphite flakes. It is generally accepted that a fine dispersed form of graphite is less deleterious than is a coarse form. Various expedients have been used to refine the graphite structure in the metal, and amongst these reference has been made already to the use of alloy additions.

One of the more important developments in recent times, however, is the principle known generally as "inoculation." This depends on the fact that if the metal is treated with certain graphitizers in the ladle, or as it leaves the furnace, a high degree of control can be exercised over the form of the graphite flakes and, by the use of additions, or inoculants as they are called, such as calcium silicide, or of ferro-silicon, a well-dispersed, fine flake form of graphite results. Such a form of graphite is associated with maximum strength properties in the castings, provided, of course, that the basic composition of the iron has been carefully selected. The exact mechanism by which inoculation is effective is not clearly understood. The process is, however, extensively used today in the production of high duty cast iron to meet modern engineering demands.

PROPERTIES OF CAST IRON AND SPECIFICATIONS

The quality of cast iron is usually measured by determining the strength of test bars. These may be cast integral with the casting they represent, or alternatively are more often cast separately, but from the same ladle of metal as the casting under inspection. Reference has been made earlier to the fact that the characteristics of cast iron of any particular composition vary with the thickness of the section into which it is cast. It is at once obvious that if a test bar cast separately is to represent the metal in the casting, then the dimensions of the bar must bear some relationship to the average section thickness of the casting, or to the most important section of metal involved.

The exact relationship between the size of test bar and the casting represented has been worked out, and the size of bars in accordance with British Standards are indicated in Table 1.4. It is standard practice in

TABLE 1.4
SIZE OF TEST BARS IN RELATION TO SECTION THICKNESS FROM B.S. 1,452

Main cross-sectional thickness of casting represented—in.	*Diameter of test bar—in.*
Not exceeding ⅜	0·6
Over ⅜ and not exceeding ¾	0·875
Over ¾ and not exceeding 1⅛	1·2
Over 1⅛ and not exceeding 1⅝	1·6
Over 1⅝	2·1

Great Britain to use a round bar with which to check mechanical properties. Given a round test bar of the correct size, this bar may be broken in the first place in a transverse bend test. For this, the bar is supported at points near either end and is loaded midway between these supports (Fig. 1.28). The bar is stressed in this manner until fracture occurs. In some cases, the degree of bend, or deflection, which takes place in the bar up to the time of fracture is measured, and is used for calculating the elasticity or springiness of the metal.

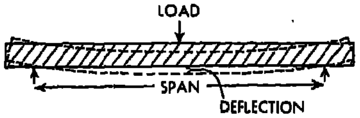


FIG. 1.28. *Principle of the transverse test.*

From the breaking load, as determined in this way, the rupture stress is calculated. The importance of using this figure to represent the transverse strength of the iron lies in the fact that all variables such as the diameter of the bar, the span of loading within limits, and so on, are reduced to a common factor, so that the rupture stress can be taken as an absolute characteristic of the metal. Whilst the transverse test is useful for quality control and checking the grade of metal in a given set of castings, the specifications today depend primarily on the tensile test carried out on test pieces machined from the appropriate size of cast bar.

BRITISH STANDARDS

The current British Standard specification covering grey iron castings is B.S. 1,452, first issued in 1948 and revised in 1956. This covers seven grades of cast iron, as shown in Table 1.5. This specification has evolved over the

TABLE 1.5

MINIMUM MECHANICAL TEST PROVISIONS FOR 1·2 IN. BAR (B.S. 1,452*)

Grade	*Tensile Strength tons/sq. in.*	*Transverse Rupture Stress tons/sq. in.*	*Deflection in Transverse Test in.*
10	10	19·3	Not specified
12	12	21·8	
14	14	24·3	
17	17	28·1	0·20
20	20	31·9	0·23
23	23	35·7	0·23
26	26	39·5	0·23

*For other sizes of bar, see Specification.

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past thirty years from the earlier specifications noted below. During this period, there has been the transition from depending largely on the transverse test, to making the tensile test the main check on quality, and using the transverse only as a subsidiary check. It should also be emphasized that the specification gives primarily a classification of the quality of the iron and cannot be claimed to represent exactly the strength given in any particular casting since, of course, design factors enter largely into the latter consideration.

Another important consideration in connexion with the specifications is that the actual composition of cast iron used for a particular job is considered to be of little importance to the purchaser and consequently British Standards have adopted the policy of leaving the chemical composition of the metal entirely to the manufacturer and of considering only the strength characteristics of the metal as the means of judging its quality.

Some record of the development of cast iron is obtained by noting the strength figures employed as the bases of specifications over the last twenty years. Thus the first specification, B.S. 321, was published in 1928, and on the 1·2 in. diameter bar, for example, strengths of 9 and 11 tons per sq. in. were quoted, these figures being regarded as a fair representation of the quality of average castings then produced.

During the period from 1928 to 1938, however, considerable progress had been made with the development of cast irons, by improved foundry control, by means of alloying, the use of inoculation, and so on. The first three grades of B.S. 786 were published in 1938, the figures for the 1·2 in. bar being 14, 17 and 20 tons per sq. in. respectively. In 1941 B.S. 786 grade 4 was added, having a strength of 23 tons per sq. in., this grade being introduced as a war-time measure to cover types of castings then available, and which would be regarded as possible substitutes for steel in applications where the toughness of steel was not essential.

After the Second World War, B.S. 321 and 786 were combined into B.S. 1,452, and a new grade with a strength of 26 tons per sq. in., was added, to cover the then available acicular cast irons. Since 1950, further rapid progress has been made with the development of spheroidal graphite cast iron, this now being covered by B.S. 2,789. This specification covers additional grades of cast iron with strengths of 27 and 35 tons per sq. in. In no other field of metallurgy can such record progress be shown. In under thirty years, the specification strength of grey iron castings has risen by over three times.

With regard to the other mechanical properties of cast iron, perhaps the most important is compressive stress, since most types of iron castings are used in a state of compression. The compressive stress for cast iron is

TABLE 1.6

MINIMUM MECHANICAL TEST PROVISIONS FOR 1⅛ in. SECTION SPHEROIDAL GRAPHITE CAST IRON (B.S. 2,789)

Type of Iron	*Tensile Strength Minimum tons/sq. in.*	*0·5 per cent Permanent Set Stress, Minimum tons/sq. in.*	*Elongation, Minimum per cent*	*Impact Value, Minimum*	
				Average ft.-lb.*	*Individual ft.-lb.*
Type 1	35	—	2	—	—
Type 2A	27	18	12	—	—
Type 2B	24	15	17	10	9

*Average of set of three on one test sample.

generally about four times the tensile strength of the metal, and ranges from about 40 to 80 tons per sq. in., or even up to 100 tons for high-duty iron. The hardness of cast iron is a property often measured, since it is of importance in judging both machinability and wearing quality. For grey iron castings the hardness is usually measured by means of the Brinell test, in which a hard steel ball is forced into the metal under a given load. The hardness is determined by measuring the diameter of the impression or indentation made. This method is that usually applied for determining the hardness of grey cast iron, although, in the case of chilled castings, the diamond indentation, or alternatively, the Shore hardness test is often applied. The latter is based on the hardness being measured by the degree of rebound of a small hammer dropped on the surface of the iron from a predetermined height. Many other properties of cast iron can be measured, but these are mainly of interest to engineers rather than foundrymen. They include such characteristics as the fatigue strength of the metal, its expansion characteristics, and so on. Many attempts have been made to develop a standard test for the toughness of cast iron. The type of test best suited for this purpose is an impact, or shock, test.

After the Second World War, an attempt was made to standardize an impact test for cast iron in B.S. 1,349. This depended on the breaking of a large bar in the normal Izod test machine. This test has, however, never been very satisfactory and the development of the tougher S.G. iron has rendered it obsolete, so that today the whole question of the impact testing of cast iron is again under review. Impact tests are often carried out on particular types of castings. These frequently are in the form of either drop weight tests or, alternatively, controlled shock tests which involve dropping the casting from a given height on to a steel or concrete floor.

For specification purposes, spheroidal graphite cast iron has been dealt with separately from general grey iron castings, and in 1956, B.S. 2,789 was issued covering two main types corresponding to the as-cast and annealed conditions of the metal. The second or annealed type is further sub-divided into two grades, according to whether maximum shock resistance is required. If such resistance is specified, then some concession has to be made on the tensile strength, as indicated in Table 1.6. The impact test, incidentally, is carried out on the normal notched-steel-type Izod test-piece.

STEEL FOUNDRY METALLURGY

STEEL is essentially an alloy of iron and carbon. For foundry purposes the carbon content in straight carbon steels is nearly always less than 0·6 per cent, although for certain special castings the carbon may even exceed 1 per cent. Steel can be regarded as a purified form of cast iron, and its manufacture is a refining process applied to charges consisting of pig iron and cast iron scrap. As previously noted, the elements normally present in cast iron are carbon, silicon, manganese, sulphur, and phosphorus. These, however, have a proportionately far greater influence in steel than they do in cast iron, even relatively small amounts having a profound effect on the properties of the metal. Consequently, they must be controlled, and in some cases eliminated to the maximum possible degree.

ELEMENTS IN STEEL

Carbon is the controlling element on which depends the properties which are ultimately obtained in the steel. The lower the carbon content, the higher the melting point of the metal and the more difficult it is to handle and cast in the foundry. On the other hand, with the lower carbon contents the steel is softer and more ductile. For foundry purposes, the carbon content is rarely below 0·1 per cent, the lowest carbon being used for electrical castings required to have specially good magnetic properties. With carbon increasing up to 0·6 per cent the liquid metal becomes more fluid and, therefore, more suitable for the production of general castings. The higher carbon gives increasing strength and other desired properties in the metal besides rendering it more responsive to heat treatment, thus further extending its range of usefulness, as will be described in detail in Chapter 2.

Silicon is usually present only in small quantities in steel, the proportion being generally less than 0·5 per cent. Within this limit silicon has not a very profound influence on the foundry or mechanical properties of the metal. Manganese, as in the case of cast iron, is generally considered a desirable element that may be present in quantities as great as 1 per cent in plain steel castings. As mentioned later, there are special steels of high manganese content. Sulphur and phosphorus, on the other hand, are both considered most undesirable in steel for general purposes. Sulphur induces hot-shortness, and tends to make the metal brittle; phosphorus also has a strong embrittling influence, and must be eliminated as far as possible. An exception to this is found in free cutting steels in which sulphur up to 0·1 per cent is allowed. Such steel is of a somewhat inferior mechanical quality. All processes of steel-making, therefore, consist, firstly, in the reduction of the undesirable impurities, such as sulphur and phosphorus, and the excess quantities of silicon and carbon normally present in cast iron; and, secondly, in the subsequent adjustment of the composition with regard to the latter elements, in order to produce the desired combination of properties.

MELTING AND REFINING

In the steel foundry, various methods of melting and refining are adopted. In some cases where the quantity of metal required is small, a steel-making process itself is not employed, and steel in suitable form, or as scrap, is merely re-melted, generally in crucible or small electric furnaces. This procedure is of strictly limited capacity but is of value where small quantities of alloyed metal are needed, since, in each case, the steel, after melting, can be readily treated with various alloy additions to produce specialized compositions. This is very true in the case of highly alloyed metal used, for example, for permanent magnet castings, for certain high-speed steels, and for some types of heat-resisting alloys. The limitations of the process, however, will be realized when it is stated that one crucible rarely holds more than 70 or 80 lbs. of steel, so that even by combining the metal from a number, it is not generally possible to produce castings weighing more than ¼ or, at most, ½ ton in weight. It is of historical interest that castings and ingots up to 70 tons weight were made by the crucible process during the latter part of the eighteenth century. This entailed the simultaneous heating of several hundred crucibles. The process was not very practical and was never widely adopted. In more recent times, steel melting in crucibles has been largely superseded by melting in electric furnaces. Both the electric induction and arc furnaces are employed in steel foundry practice.

Electric induction furnace melting allows the production of larger quantities of steel than does crucible melting, and furnaces are in operation up to 10 tons capacity.

The more usual practice in the steel foundry is to employ a true steel-making process, either in open-hearth furnaces, in electric arc furnaces, or in converters. Large open-hearth furnaces are used where large castings are being produced. These furnaces, such as the Siemens furnace, may have a capacity of over 100 tons. Their use in the foundry is usually restricted to the production of large size castings, as, for example, ships' castings, large electric motor frames, and castings for general engineering purposes such as hydraulic cylinders, riveter frames, flywheels, large gears, and so on.

For the production of smaller quantities of metal, electric arc furnaces are used extensively, but the utilization of this type of melting furnace is much more the practice in the United States than in Great Britain, the furnaces often being employed in duplexing processes taking partly refined molten metal from the cupola and converters. A more common method used in Great Britain is by means of converters, as, for example, the Bessemer converter, the Tropenas or Stock converters. The production of steel in the open hearth, the electric arc furnaces and in converters is a true refining process using as raw material pig iron or cast iron scrap mixed with a proportion of steel scrap. Each process consists essentially in the oxidation of the various impurities out of the molten bath of metal, burning out the carbon, oxidizing silicon to silica, which forms a molten slag on the surface of the bath, and oxidizing the manganese which also goes into the slag.

The steel-melting processes are divided broadly into two groups, known respectively as *acid* and *basic*. Each process can be worked in each type of steel furnace referred to above. The essential difference between the two processes is that in the acid process the lining of the furnace and the slag are siliceous in character. Under oxidizing conditions, silicon and manganese both pass into the slag, but a siliceous slag will not remove sulphur and phosphorus. It is, therefore, essential in selecting the raw materials for the acid process that these latter elements should be at a minimum and less than allowed in the finished steel product, as a small concentration occurs, due to the melting loss of iron, carbon, silicon and manganese.

In the basic process the treatment of the molten bath is conducted in the presence of a magnesite or dolomite furnace lining and a lime slag, as opposed to materials predominantly siliceous in the acid process. Under these conditions phosphorus is reduced in the metal forming a calcium phosphate slag. Obviously, a great advantage of the basic process lies in the fact that a far greater choice of raw materials is available.

SIEMENS MELTING PROCESS

This is the process normally employed in the production of large quantities of molten steel, and is carried out in large open-hearth furnaces equipped with regenerative systems for preheating the air and gas supplies for working the furnace. The charge is generally of steel scrap and pig iron, which are melted down in the hearth of the furnace. The process consists in oxidizing out the carbon, silicon and manganese from the bath by the addition of iron ore, the ore, of course, being reduced to metallic iron which is absorbed by the bath. The oxygen thus liberated, together with the oxygen in the furnace gases, withdraws silicon and manganese into the slag, and oxidizes the carbon, which burns on the surface of the bath, ultimately to carbon dioxide. Both the acid and basic processes may be worked in furnaces of this type. In the case of the acid process, however, the charge must, as indicated, be low in both phosphorus and sulphur.

In the basic process, on the other hand, phosphorus is removed from the molten metal, being withdrawn into the slag as calcium phosphate. In some cases, the quantity of lime used for slag formation is restricted during the early part of the process, so as to accelerate, initially, the oxidation of carbon, silicon and manganese, whilst the quantity of lime is later increased toward the end of the process, the phosphorus being removed at the last stage.

In the basic open-hearth process the hearth of the furnace is made up with dolomite or magnesite, and a limestone flux is employed to form the slag. Oxidation takes place with the addition of iron ore as above, and the removal of carbon, silicon and manganese follows in a similar manner. Phosphorus, however, is also removed into the slag in the form of calcium phosphate. In both processes, acid and basic, the combined effect of the oxidizing actions is to raise the temperature of the bath. When refining is complete, the bath is highly oxidized; deoxidation is effected by the addition of ferro-silicon, ferro-manganese, or silico-manganese, which remove the excess oxygen from the bath with the formation of a certain amount of fresh slag.

ELECTRIC ARC FURNACE

Various types of electric arc furnaces are used for steel production. These are mostly of the Héroult type and modifications of it. In brief, the steel-making process is the same as in the open-hearth furnaces, except that the source of heat whereby the charge is melted is the electric arc struck generally between the bath and electrodes passed through the furnace roof. In the electric furnace, both the acid and basic processes are used, the furnace lining being made up as required, and the slag controlled to suit the process being worked. In the acid process the charge consists of scrap and pig melted down under conditions as above. Iron ore is used as the oxidizing agent forming oxidizing slags from which iron oxide enters the bath and leads to the removal of the carbon from the metal by the boil.

The final adjustment of the composition of the steel before tapping is usually effected by the addition of suitable pig iron of low phosphorus and sulphur content. Final deoxidizing and killing of the bath is carried out by means of ferro-silicon and ferro-manganese additions. The electric arc furnace is used, chiefly, in the production of alloy steels of special analysis, as, for example, high manganese and chromium steels.

CONVERTERS

The method of producing steel in converters was developed in the early days of steel-making. The process consists essentially in the treatment of molten pig iron or scrap of controlled composition in pear-shaped vessels into which air is blown either through the bath from the bottom of the vessel or from the side of the converter over the surface of the charge. The original converter was that developed by Bessemer, in which the charge previously melted in cupolas similar to the ordinary foundry cupola, or in electric furnaces, was treated by blowing the air through the bottom of the converter. Bessemer converters have capacities up to 50 tons. Nowadays, more extensive use is made in Great Britain of the process as developed by Tropenas in the type of converter bearing his name, or the Stock converter. These are of smaller size than the Bessemer converter, being generally of 15 cwts to 5 tons capacity, and differ mainly from the latter in the fact that they are side blown instead of bottom blown.

In the acid converter process, a charge low in sulphur and phosphorus must again be selected. It should, however, be mentioned at this point that some reduction in sulphur is possible in these steel-making processes by the treatment of the molten charge by means of soda-ash, added, generally, to the metal from the cupola before running it to the converter. The molten metal is transferred from the cupola in a ladle in which desulphurization may be carried out, and is then poured into the converter and air is blown through the charge. The three elements, silicon, carbon and manganese are rapidly burnt out of the iron, the order of removal of these being indicated in Fig. 1.29. From this it is seen that the tendency is for the manganese to burn out first, the silicon next and, finally, the carbon to be removed from the charge. The oxidation of these elements is accompanied by a substantial rise in temperature, so that whilst the charge may be introduced to the converter at ordinary iron foundry temperatures, namely 1,300 to 1,400 deg. C., after the charge is blown, this temperature will rise to that of the steel foundry, somewhere between 1,550 and 1,650 deg. C. After blowing, the metal composition is adjusted by means of ferro-manganese and ferro-silicon. As described already, final deoxidation is carried out in the ladle by means of aluminium, calcium silicide, or ferro-titanium.

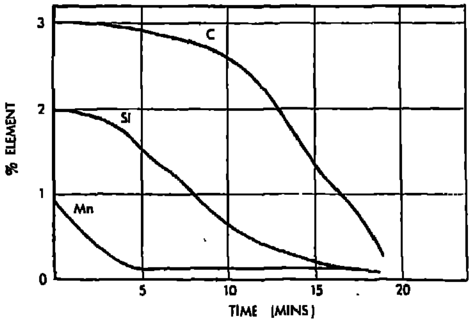


FIG. 1.29. *The rate of removal of the three elements silicon, carbon and manganese, from steel in the converter process. (Proc. I.B.F.)*

The main reactions in the converter are as follows:

(*a*) Oxygen of the air combines with some of the iron, giving iron oxide with the evolution of a considerable amount of heat.

(*b*) The iron oxide passes on its oxygen to the carbon present, carbon leaving the bath as carbon monoxide with the evolution of more heat.

(*c*) The carbon monoxide burns on the surface of the bath with more air to form carbon dioxide with a further rise in temperature.

(*d*) Iron oxide reacts with the manganese present, forming manganese dioxide, which passes into the slag.

(*e*) Iron oxide reacts with the silicon forming silica, which also passes to the slag.

In the secondary reactions, *b*, *d*, and *e*, more heat is evolved and, as the oxygen is passed from the iron to the impurities, so pure iron is returned to the bath, and, at the end of the blow, the bath consists of almost pure iron mixed with a certain amount of excess iron oxide. The excess oxygen present in the bath is removed by the addition of ferro-manganese, ferro-silicon, and aluminium, etc., as described above. The losses in the converter vary considerably, being between 5 and 15 per cent of the total metal charged to the vessel. To this must be added the melting loss in the cupola.

In all the steel-making processes, alloys may be added in small proportions to the bath after melting is completed. This applies particularly to the addition of small quantities of nickel, chromium, and so on. Molybdenum, on the other hand, is added during melting. If, however, more highly alloyed steels are required, as, for example, those containing substantially high quantities of manganese, chromium, or nickel, then the addition generally must be separately melted, since clearly the temperature of the bath would fall below the limit for use in the foundry if heavy additions of cold metal were made after the refining process. Some idea of the compositions of steel produced in the foundry and the associated properties are given in Table 1.7.

TABLE 1.7 ANALYSIS, HEAT TREATMENT AND

Class	*Type*	*Typical analysis*							*Heat treatment to give service condition*
		C	*Si*	*Mn*	*Ni*	*Cr*	*W*	*Mo*	
Carbon steel	0·20% C.	0·21	0·27	0·69	—	—	—	—	Annealed 900° C.
Carbon steel	0·30% C.	0·32	0·24	0·73	—			—	Annealed 890° C.
Carbon steel	0·40% C.	0·39	0·26	0·64	—	—	—	—	Annealed 860° C.
Carbon steel	0·60% C.	0·62	0·22	0·66	—	—	—	—	Annealed 840° C.
Carbon steel	0·75% C.	0·73	0·27	0·69	—	—	—	—	Annealed 810° C.
Alloy steel	1½% Mn (*a*) 0·25% C.	0·23	0·31	1·41	—	—	—	—	Annealed 920° C.
	1½% Mn (*b*) 0·45% C.	0·43	0·24	1·36	—	—	—	—	Annealed 900° C. O.H. 870° C. T.600/650° C.
Alloy steel	Ni-Cr	0·36	0·28	0·53	1·62	0·76	—	—	Annealed 900° C. O.H. 870° C. T.550/650° C.
Alloy steel	Ni-Cr-Mo	0·32	0·23	0·72	1·87	0·78	—	0·38	Annealed 900° C. A.H. 870° C. T.550/650° C.
Alloy steel	C-Cr	0·43	0·29	0·58	—	0·89	—	—	Annealed 900° C. O.H. 870° C. T.550/650° C.
Rustless steel	14% Cr stainless	0·29	0·48	0·53	—	13·4	—	—	O.H. 960/890° C. T.700/750° C.
Rustless steel	18% Cr, 2% Ni stainless	0·17	0·31	0·57	1·7	17·9	—	—	O.H. 960/990° C. T. 500/550° C.
Acid-resisting steel	18% Cr, 8% Ni	0·10	0·73	0·38	8·2	18·4	0·63	—	A.C. or W.Q. 1150° C. A.C. or W.Q. 1050° C.
Heat-resisting steel	26% Cr 10% Ni	0·14	1·6	0·49	10·2	25·8	—	—	A.C. 1050° C.
Heat-resisting steel	20/25% Cr 8/12% Ni 3/4% W	0·14	1·76	0·43	11·4	23·9	3·2	—	A.C. 1050° C.
Heat-resisting steel	30% Cr	0·29	0·97	0·67	—	29·6	—	—	O.H. 1050° T. 600/700° C.
Heat-resisting steel	Nichrome (60:20:20)	0·97	0·84	1·12	63·8	22·1	—	—	A.C. 1000° C.
High permeability steel	Low C	0·09	0·32	0·10	—	—	—	—	Annealed 900° C.
High temperature steel	Mo (*a*) 0·20% C.	0·18	0·24	0·63	—	—	—	0·51	Annealed 900° C. A.H. 870° T. 650° C.
	(*b*) 0·30% C.	0·32	0·36	0·78	—	—	—	0·58	Annealed 900° C. A.H. 870° T. 650° C.
Shock-resisting steel	Mn-Mo	0·25	0·26	1·43	—	—	—	0·54	Annealed 900° C. A.H. 870° T. 650° C.
Wear-resisting steel	C-Cr	0·73	0·34	0·81	—	1·62	—	—	Annealed 920° C. O.H. or A.H. 870/900° C. T. 550/650· C.
Wear-resisting steel	Austenitic Mn	1·07	0·72	12·8	—	—	—	—	W.Q. 1000° C.

Note. The key to the abbreviations used in this table is given on Table 2.6, *p*. 83.

APPLICATIONS OF STEEL FOUNDRY ALLOYS

Mechanical properties					*Applications*
M.S. Tons per sq. in.	*Y.P. Tons per sq. in.*	*Elong. per cent*	*R. of A. per cent*	*Brinell Hardness*	
26/30	13/17	35/20	55/30	111/126	Structural and engineering mild steel castings.
29/34	14/18	28/18	45/24	121/149	Higher tensile general castings.
35/40	18/21	20/15	30/18	159/179	General castings for wear resistance.
45/50	—	—	—	196/225	Cast steel die-blocks, anvils, hammer tups, cast steel hammer and press tools.
50/55	—	—	—	225/255	
35/40	18/22	23/18	35/25	159/179	Tough steel castings for gears, digger teeth and abrasion-resisting details.
40/50	20/28	15/10	25/15	183/229	
50/60	30/40	15/10	25/15	229/277	
40/50	25/35	15/10	25/15	183/229	Castings with maximum strength and toughness for gears and machinery details.
50/60	35/50	18/10	30/15	229/277	
40/55	30/45	15/10	25/12	183/248	For gear blanks, and other details for toughness and wear-resisting purposes.
40/45	20/25	25/20	45/35	183/207	Hydraulic and steam plant details, including valves.
45/50	28/32	18/15	30/20	207/228	Highly stressed castings, subject to corrosive conditions.
32/37	15/17	45/25	45/25	143/170	Chemical castings and decorative details required for corrosion resistance.
37/42	16/19	25/15	25/15	170/192	
34/38	16/18	25/20	30/25	156/174	Furnace details and other parts required to resist heating.
35/40	17/20	25/20	30/25	163/183	Furnace and stoker details required to possess strength at high temperatures.
26/30	—	—	—	114/131	Heat-resisting castings for maximum resistance to oxidation.
22/32	18/27	10/2	—	138/180	Electric resistance wires, annealing boxes and other parts requiring maximum heat resistance.
24/28	13/16	35/25	55/35	103/116	Electric machinery castings with good magnetic properties.
32/38	17/26	26/20	42/30	143/174	High-temperature steel, high-pressure steam-plant turbine casings, etc., highly stressed at super-heat steam temperatures.
34/42	18/28	25/18	40/28	156/192	
40/50	25/35	20/12	30/18	183/229	Shock-resisting steel for maximum shock resistance, e.g., in mining and excavating machinery.
—	—	—	—	201/321	Grinding and milling machinery details and parts subject to attrition.
—	—	—	—	241/401	
—	—	—	—	241 max.	Crusher plates, rolls, etc., subject to abrasion.

(From "Steel Castings, with special reference to Alloy Steels," W. Hatfield. Proceedings of The Institute of British Foundrymen.)

Chapter 2

HEAT TREATMENT IN THE FOUNDRY

HEAT treatment is applied to castings for two main purposes: firstly, for the relief of stresses which may be set up in the metal due to unbalanced contraction effects arising during cooling, or to the results of accelerated cooling, as in chilling, quenching, and so on; and secondly, for the modification and control of the structure and constitution of alloys as cast in the foundry. Recent developments in alloy and special cast irons and in particular in the new S.G. irons have emphasized the importance of heat treatment in the foundry. Castings in many of these newer materials require some form of heat treatment in order to develop their best properties.

When liquid metal is cast into a mould it contracts as it cools till the solidification temperature range is reached. When freezing commences, further contraction takes place, due to the fact that the solid metal is normally less in volume than the liquid from which it has formed. This explains the need for using feeding heads on castings, as explained in Chapter 8, since, throughout the liquid cooling range and during solidification, fresh liquid metal must be fed to the body of the casting, otherwise voids or cavities due to the contraction of the liquid metal will be found in the casting when solid. Provided adequate feeding has been ensured when the metal is hot, a complete impression will be taken of the mould, and internal contraction cavities in the casting should be absent. Once solid, the hot metal in the mould continues to contract as it cools, until it reaches room temperature.

CASTING STRESSES

As the hot metal cools it must be free to shrink or contract in all directions, because if the shrinkage is hindered in any way, stresses will be set up in the metal which, in extreme cases, may cause fracture, the casting being found cracked, or even broken, when the mould is opened. On the other hand, the metal may be continuous but show small cracks known as hot tears, either on the surface or in the body of the metal as cast. In practice, these types of foundry defects must be avoided. They can, to some extent, be met by such provisions as the use of collapsible cores and

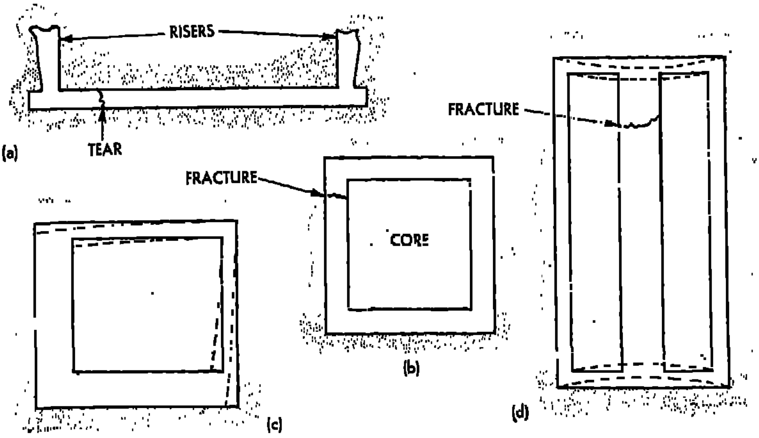


FIG. 2.1. *Some examples of hot tears and casting stresses.*

the avoidance of hard-rammed moulds. There are, however, very few types of castings in which there will not be some stresses, known as casting stresses, left locked up in the metal when the casting is cold. This will be appreciated when it is realized that it is generally impossible, in practice, to allow unhindered contraction in all parts of a casting, especially as the thinner and more quickly cooling parts reach a lower temperature and are, therefore, more rigid earlier than are the thicker and more slowly cooling parts.

In almost all castings, therefore, and especially in those of the higher melting point metals (due to their longer cooling range), and in the harder alloys (due to the more rigid nature of the metal), stresses must to some extent be expected. The degree to which these stresses develop depends upon the type of casting, and especially on the range of section thicknesses involved.

Some examples of ways in which casting stresses may be set up are shown in Fig. 2.1. In (a) part of the casting is shown lying between two risers. These risers may be rigidly held either by other parts of the mould, or the sand between them may be rammed so hard that it does not collapse as the part of the casting between the risers tries to contract. This is a common cause of hot tearing, or if this is avoided, of stresses left in the metal when cold.

In example (b) it is seen that part of the casting surrounds a core. This is, of course, common in practice. As the sides of the casting tend to contract on cooling, the size of the square shown must be allowed to diminish. This is taken care of normally by the use of collapsible cores, i.e., by the use of cores in which the centre part consists of loosely packed coke or other crushable material. If the core consists of hard-rammed sand which cannot yield while the casting cools, then it is almost certain that the final casting will be full of stresses, if not actually broken.

In example (c), somewhat similar in shape to (b) except that two sides of the square are of relatively heavy section as compared with the other two sides, the two thinner sides of the casting become solid and rigid, even before the thicker sides may have completed solidification. As the thicker parts cool, therefore, their contraction will, to some extent, be resisted by the more rigid part, and once again stresses will be set up in the form of tension in the thick parts which may be seen in the form of actual bending or distortion of the thinner sides. The trouble in this case, whilst similar to (b), is aggravated by the variation in section thickness.

In (d) a simple form of test casting is used to demonstrate the effects of casting stresses. In this the heavy section in the centre of the casting will be the last part to solidify. The lighter members with which it is surrounded will all become rigid before solidification takes place in the centre. The contraction of the centre part will, therefore, be resisted by the rest of the casting, and once again the centre member would be left in a state of tension as shown by the curvature found in the cross members at the top and bottom of the casting. The stresses and distortion occurring in such castings will all be greater in metal which has a high solidification temperature and which, therefore, has a long temperature range during which shrinkage must take place. It is not, therefore, surprising to find that the troubles arising from casting stresses, including both fracture in the mould and hot tears, are more common with steel than they are with cast iron, and in the latter case are also more serious than in the various non-ferrous metals cast at relatively lower temperatures. Casting stresses lead to distortion and warpage. If this distortion has taken place before the casting leaves the foundry it may be rectified in machining. Sometimes in steel, distortion may be corrected by the application of force, to bend the casting back to shape.

The solid contraction of a casting is, of course, allowed for in pattern-making. The allowance for pattern shrinkage for ferrous metals is generally between ⅛ in. and ¼ in. per foot length, but may be less in some special cases, e.g. in thin castings in S.G. iron which are subsequently annealed and which expand on annealing so that for some designs the actual pattern shrinkage may be nil.

In many cases the casting, as received from the foundry, may still contain locked-up stresses, and when it is put into service these stresses may be gradually released, causing changes in dimension which may be extremely harmful. Another factor which must be borne in mind is that parts which are initially stressed are unnecessarily weak and brittle in service, and may fail on the application of relatively low loads and especially under shock. This, of course, is easily explained when it is realized that the centre of the casting shown in Fig. 2.1 (d), for example, may be already stressed to a considerable extent, thus reducing the useful additional loading which it will take.

ANNEALING

The cure for all the troubles resulting from casting stresses is *stress relief annealing*. This is described in connexion with the various foundry alloys below.

In the above consideration it has been assumed that after solidification the metal tends to contract more or less uniformly until the casting has reached room temperature. In the case of many foundry alloys, however, the metal undergoes internal structural change during the cooling process. Thus in iron and steel the body of the metal at high temperatures is initially austenite. In the temperature range between 900 and 700 deg. C., austenite transforms to pearlite, or if alloys are present the transformation may take place at lower temperatures when other products than pearlite and such as martensite may be formed. The essential point is that where any substantial internal change takes place in the metal there is normally an accompanying volume change. This in itself may set up extra stresses in addition to the normal casting stresses referred to above, especially in castings of varying section thickness. Another important feature is that all the constitutional changes taking place in metals depend, to some extent, on the time factor, and in castings of thin section the change may not be complete if the cooling rate is high. The castings on reaching room temperature may, on this account, be unstable and, in addition, show undeveloped properties. The type of heat treatment known as annealing is intended primarily to stabilize the structure by allowing any transformation to proceed to completion, as well as to release casting stresses.

In the second case the prolonged heat treatment of materials such as cast iron is used to bring about a definite change in structure and properties. Thus, structures which would normally be considered as stable at room temperatures can be modified by holding the metal at elevated temperatures for considerable periods of time. No better example of this could be found, perhaps, than in the malleabilizing process in which an iron which has initially been cast in the form of a white iron casting is treated for a long time at an elevated temperature, and sometimes in the presence of oxidizing agents, all of which result in the break-down of the hard carbide constituents of the iron, giving ultimately a strong soft product known as malleable iron. In grey cast irons, heat treatment is often employed to break down excess carbides in order to ensure free machining at high speeds. This applies particularly to certain classes of light castings made by repetition methods in which no particular mechanical properties are required except that they shall be easily machined. This condition is met by a high temperature annealing described in detail below.

As a further example of the modification of the properties and structure of cast alloys, mention may be made of some of the newly developed metals which are known as the precipitation hardening alloys. Very briefly, these are metals in which one constituent is soluble in another at elevated temperatures, but at lower temperatures the solubility falls, so that either the second constituent must separate out or remain in a state of supersaturation. It has been established that many alloys in all branches of metallurgy show this phenomenon, though the most useful are mostly non-ferrous. This leads to the type of heat treatment known as ageing, or precipitation hardening. Thus, an alloy in this class can be quickly cooled from high temperatures, in which case the matrix will be supersaturated in respect of the less soluble constituent. If the casting is now heated to a relatively low temperature and held there for some time, the separation of the second constituent is brought about under controlled conditions. This precipitation, in many cases, can be made to result in substantial increases in the hardness and strength of the casting.

In the last, and perhaps the most common, type of heat treatment applied to foundry practice, use is made of the fact that where constitutional changes take place in a metal on cooling, then it is possible, by accelerating the cooling, frequently to suppress completely the change which would normally have taken place. Alternatively, the change which would take place at high temperatures can be forced to take place at much lower temperatures, in which case a different set of properties can be developed. This type of heat treatment is best represented in the quenching and tempering treatment as applied to iron and steel. In this a steel, for example, is heated to a temperature generally in excess of 850 deg. C., and is rapidly cooled from that temperature by quenching in water or other suitable medium. This brings about a marked change in the properties of the material, but some of the properties as, for example, shock resistance, may be adversely affected. This can be rectified by a further treatment known as tempering, in which the part is reheated to a low temperature.

Further consideration will now be given to these various types of heat treatment in respect of the various groups of foundry products considered elsewhere in this book. It is of interest to note that most of the types of heat treatment described in the introductory section of this chapter are applied to cast iron, except the specialized treatment mentioned as precipitation hardening.

HEAT TREATMENT OF CAST IRON

The three main purposes of the heat treatment of cast iron are: (a) A high temperature heat treatment to alter the constitution of the metal as, for example, in malleabilizing; (b) Stress relief annealing, and (c) Quenching and tempering to improve the mechanical properties. The first type of heat treatment is used largely in the production of malleable iron castings which forms a substantial and important section of the iron foundry industry, and which has been used for many years past to produce a product in which the deleterious effects of coarsely graphitic structures are overcome. In this industry other specialized types of heat treatment are also used. These aim to produce irons of exceptional strength from, initially, a low carbon product by carefully controlling the form in which the carbon is developed in the final casting. These last processes are of an academic rather than a practical nature, and need not be considered here.

In the early days of the iron foundry industry, many attempts were made to overcome the inherent brittleness of the relatively coarse-grained types of iron produced in the foundry. As early as in 1722 it was found that if white-iron castings were packed in hematite iron ore and heated to a bright red heat for many days, the resulting castings possessed properties much more akin to steel than cast iron, in that they showed a high degree of toughness and the castings were bendable or malleable. Since that time the malleable industry has developed extensively. Up to a short time ago, two main processes were in use called, respectively, the Whiteheart or European process, and the Blackheart or American process.

WHITEHEART MALLEABLE CAST IRON

In the whiteheart process, white iron castings are produced in the foundry using careful control over the composition so as to give castings which are white throughout, and which are substantially free from any graphitic carbon. Since, in the final treatment of the castings, it is necessary to break down the white structure with its massive iron carbides to the grey temper form, clearly the composition should be selected so that whilst the castings are completely white initially, they will be reduced to the grey form as easily as possible in the heat-treatment cycle. This necessitates a careful adjustment of the composition, especially with regard to silicon, and bearing in mind the section thickness.

The analysis of the white iron castings calls for no special comment otherwise, beyond saying that since low silicon pig iron is generally high in sulphur, this element is usually abnormally high in malleable iron, running anything up to 0·25 per cent. The effect of sulphur is to stabilize the carbides, so that its influence must be counteracted to some extent by modification in the silicon content. The complete analysis of a white iron casting prior to malleabilizing in the whiteheart process is shown in Table 2.1. For the malleabilizing treatment the castings are packed into canisters with a mixture of fresh and partly used hematite ore. The canisters are stacked into kilns, or furnaces, and heated gradually to about 900 deg C., at which temperature they are held for some five or six days. The furnace is then slowly cooled and the castings are removed and cleaned.

The difference between the whiteheart process and other processes for the production of malleable cast irons consists essentially in the action of the hematite ore on the castings. Contact with the ore results in a gradual migration of carbon from the heart of the casting to the skin where it is oxidized and removed from the metal. In the whiteheart process, therefore, the final product has a low carbon content, this being frequently less than 1 per cent in castings of thin section (Table 2.1). The balance of the carbon is present partly in a nodular form of free graphite and partly combined, the latter appearing in the final structure as pearlite in the matrix of the metal (Fig. 1.18).

BLACKHEART PROCESS

The blackheart process, for the production of malleable cast iron, differs essentially from the whiteheart process in that no ore is used in the treatment of the castings, and consequently the carbon content of the metal is not appreciably reduced. A low sulphur content is also necessary in the raw castings. The castings are packed into canisters, if necessary with a neutral packing material, and are then gradually heated in an annealing furnace to a temperature of 820 to 1,000 deg. C., held there

TABLE 2.1

TYPICAL ANALYSIS OF MALLEABLE CAST IRON

	WHITEHEART		BLACKHEART	
	As cast	*Annealed*	*As cast*	*Annealed*
Total carbon	3·2–3·6	0·5–2·0	2·3–2·6	2·1–2·4
Combined carbon	3·1–3·5	0·3–0·8	2·2–2·5	0·1
Silicon	0·4–0·8	0·4–0·7	0·9–1·1	0·9–1·1
Manganese	0·15–0·3	0·15–0·3	0·3–0·4	0·3–0·4
Sulphur	0·15–0·25	0·15–0·25	0·06–0·1	0·06–0·1
Phosphorus	0·05–0·08	0·05–0·08	0·1 max.	0·1 max.

TABLE 2.2
PROPERTIES OF WHITEHEART MALLEABLE CAST IRON 0·564 in. TEST BAR (B.S. 309: 1957)

	Grade I	*Grade II*
Ultimate Tensile Strength	22 t.s.i. min.	24 t.s.i. min.
Yield Point	12 t.s.i. min.	13 t.s.i. min.
Elongation	4% min.	8% min.
Angle of Bend around 2 in. dia. mandrel	45° min.	90° min.

TABLE 2.3
PROPERTIES OF BLACKHEART MALLEABLE CAST IRON 0·564 in. TEST BAR (B.S. 310: 1957)

	Grade I	*Grade II*	*Grade III*
Ultimate Tensile Strength	18 t.s.i. min.	20 t.s.i. min.	22 t.s.i. min.
Yield Point	10 t.s.i. min.	11 t.s.i. min.	12 t.s.i. min.
Elongation	6% min.	10% min.	14% min.
Angle of Bend around 2 in. dia. mandrel	30° min.	90° min.	135° min.

for three to six days, and allowed to cool slowly. This gives a product in which, although some carbon may be removed by oxidizing, this is immaterial to the process and the carbon content of the final casting is more nearly approaching that of ordinary cast iron. In the annealing process the carbon is precipitated in a finely divided form (temper carbon), which interferes only to a minor extent with the mechanical properties of the matrix, thus giving a product much more like steel than normal grey cast iron (Fig. 1.9). The analysis of typical blackheart castings after annealing is given in Table 2.1.

MODERN MALLEABILIZING PROCESSES

Within recent years considerable attention has been given to the mechanization of the annealing process in malleabilizing, and as a result a number of improvements have been made. It has been realized, for example, that very careful control is necessary over the cooling time, especially in the critical temperature range lying between 950 and 750 deg. C. Modifications in the malleabilizing technique have been concerned mainly with the introduction of modern furnaces giving greater control over the heat treatment operation, and today a large tonnage of malleable iron is produced in continuous types of kilns in which the castings are packed in containers on to bogies, which are pushed continuously through tunnel furnaces of such length that during their passage the charges pass through the complete annealing treatment cycle.

Another modification of considerable importance has been the introduction of the so-called short cycle malleable irons in which very careful control over the heating cycle has enabled a substantial reduction in the annealing time necessary for the production of the finished castings. This is coupled also with the use of certain alloys which are introduced primarily to improve the properties of the matrix of the metal after treatment, and secondly, also to assist the control of graphitization. In the second place it is realized that frequently excellent properties can be obtained where the malleable process has not been carried to a final state of completion, and where sufficient control is available it is better to stop the treatment in an intermediate stage, thus saving time and increasing the productive capacity of the plant.

The minimum mechanical properties specified in the revised British Standards for whiteheart and blackheart malleable cast irons are indicated in Tables 2.2 and 2.3.

Malleable cast iron is used for a large number of engineering details and is particularly suitable where something stronger and tougher than grey cast iron is required, but where cheapness is essential. Compared with other materials, malleable cast iron is lacking in corrosion resistance, but its other properties make it admirable for many parts subjected to shock, as, for example, in many cycle and motor car details and in general engineering equipment.

Malleable castings are now meeting some competition from the newer spheroidal graphite cast irons, due in particular to the toughness and ductility which the latter exhibit and which, under suitable conditions, can be obtained in the castings as cast, or after a short, simple heat treatment. The S.G. irons are suitable for many parts previously made in malleable; in addition, the new irons show a higher yield strength than does malleable and are of special interest as they do not suffer the section-thickness limitations which apply in malleable cast iron.

ANNEALING FOR MACHINABILITY

It may often happen in the foundry that, due to a wide variation in the section thickness of a casting, or alternatively, to some miscalculation in regard to the composition of the metal used for the castings, they may be found to be too hard for machining, especially at corners and edges. This is frequently taken care of by the use of those alloy additions which confer a greater latitude on the metal and thus avoid wide structural differences between the varying sections. In other cases, however, it may be desirable, on account of cheapness or for other reasons, to obtain the necessary machining qualities by a simple and quick annealing process. This applies especially to work involving thin sections and in which mechanical strength is of secondary importance, the prime necessity being that the castings should be capable of being machined at high speed.

The annealing treatment involved aims essentially once again at breaking down the excess carbides present in the metal. It differs from the malleable process, however, in that no precautions are taken to ensure the absence of graphitic carbon from the castings as produced, and secondly, in that the heat treatment is carried out over a short time cycle so as to break the carbides down as rapidly as possible. As a result, a flake rather than a nodular type of graphite is formed, and the castings therefore show none of the ductility of malleable ones. For conferring machinability where the castings are hard, or where heavy cuts are required and strength is of secondary importance, the castings are heated rapidly to a temperature of about 800 deg. C., and slowly cooled. It must be remembered that this treatment, whilst usually effective in breaking down the excess carbides in the metal, tends to spoil the mechanical properties of the iron by lowering its strength and hardness to an appreciable extent. Such treatment is, therefore, not permissible on high-duty castings of the flake graphite type.

STRESS RELIEF ANNEALING

The second type of heat treatment frequently given to cast iron today is stress relief annealing. In this no structural modification of the metal is induced. Reasons for the necessity for treatment of this type have already been detailed. With the modern high-duty flake graphite types of cast iron there is, perhaps, a greater tendency toward the development of casting stresses, especially in casting of complicated design, than with more common grades of metal. On the other hand, the service demanded of modern castings is being gradually increased, so that where high-duty castings are used it is frequently under conditions where a higher degree of stability and endurance is called for than ever before. For these reasons stress relief annealing has been receiving more and more attention, and is being specified to an increasing degree for many types of castings, including machine-tool parts, jigs and tools, cylinders, engine castings, and so on. In all these cases harmful distortion may develop in service from the gradual relief of locked-up stresses. In castings as for machine tools the relief of the internal stresses is essential to ensure stability, and for this reason it has been the practice of engineers in the past to demand that castings of this type should be aged, or weathered, by leaving them out-of-doors for a sufficiently long period to release, at least in part, the locked-up stresses which might normally cause distortion.

Stress relief annealing as practised today, however, ensures stability of the castings by a short heat-treatment cycle, thus eliminating any delay and inconvenience arising from the need to store the castings for weathering over long periods of time. As already mentioned, some of the modern high-duty cast irons are more prone to show internal stresses than more common irons.

The use of alloys, and especially nickel by its action in equalizing the structure in varying sections of a casting, helps to avoid casting stresses, and thus reduces the need for stress relief annealing. Conversely, hardening elements such as chromium which tend to give a stable carbide in the thin sections of the casting, would be expected to cause the incidence of greater casting stresses. White iron, similarly, on account of its short freezing range, rigid structure and higher contraction, is more liable to show casting stresses than grey cast iron.

Stress relief is usually achieved in iron castings of all types by heating them slowly in a core oven, or other type of furnace, until a temperature between 500 and 600 deg. C. is obtained. They are then held at this temperature for a period corresponding to about one hour for each inch of section thickness. After this the castings are slowly cooled in the furnace. This treatment is sometimes applied after fettling, or even after rough machining. Provided that the treatment is given in accordance with the above notes, there should be no appreciable residual stresses after the castings have cooled.

It is important that in stress relief annealing the castings should not be heated to a temperature in excess of the upper limit of 600 deg. C. indicated, since above this temperature the structure of the metal starts to break down, and the mechanical properties of the iron will be lost. It is, therefore, useless to produce high-duty castings and then subsequently anneal them at a temperature, say, of 800 deg. C. in order to improve machinability, as the loss in mechanical strength may result in the casting failing to meet the desired strength.

Generally speaking, if the stress relief annealing is carried out properly, some increase in strength and toughness may result from the treatment. In simple types of castings the increase may be between 2 and 5 tons per sq. in., but in complicated castings, where the locked-up stresses may be initially high, the increase in strength may be substantially greater, especially when the increase in toughness is measured by an impact test. This will be clearly understood when reference is made to Fig. 2.1 showing the casting in which a heavy section is restrained in cooling by a lighter frame. In this case the casting may, when cold, be strained toward the breaking point of the thick section so that a stress of only 3 or 4 tons per sq. in. might be sufficient, when added to the existing stresses, to break the bar. Similarly, a relatively light impact would have the same effect. The inherent strength of the iron used for the casting may have been 20 tons per sq. in., and with stress relief annealing, it would be expected that this would be the ultimate strength of the casting. In this case, therefore, the increase in strength shown by the middle section on stress relieving would be from 5 to 20 tons, i.e., a gain of 15 tons per sq. in. with corresponding increases in impact strength.

QUENCHING AND TEMPERING

It has long been known that the carbon steels can be appreciably modified and improved by heat-treatment operations such as quenching and tempering. This treatment is generally used to effect improvement in the hardness of the casting, and also to increase toughness and strength by suitable manipulation of the treatment. Attempts have been made from time to time to apply the same treatment to cast iron, but in the early days these did not meet with much success, mainly because the cast iron selected was of relatively poor quality. As a result very severe stresses were set up in the quenching treatment and, generally, fracture of the casting occurred. (The quenching stresses are similar in kind to the casting stresses already considered.)

Today the improvement in the quality of cast iron has rendered the metal better able to withstand the stresses set up in quenching, so that in simple parts, and especially those of light section, it is now quite feasible to raise the strength and hardness of the finished component by quenching and tempering. Of greater importance, however, is the fact that by the use of alloys it has been found that, as in the case of the alloy steels, the field of heat treatment has been substantially widened. Certain alloy elements, notably nickel, facilitate heat treatment. This will be realized when it is recalled that the addition of nickel up to about 4 or 5 per cent develops the martensitic structure in castings as removed from the moulds in the foundry. This structure (illustrated in Fig. 1.20) is similar to that aimed at in the heat-treatment operation. One of the fundamental effects of nickel is so to improve the heat-treatment properties of the iron that with increasing amounts of nickel an appreciably milder type of treatment can be used to achieve a given result. Thus, whilst with an ordinary iron, water quenching is necessary for a given result, with a 1·5 per cent nickel iron, similar properties can be achieved by quenching in oil, whilst at 3 per cent of nickel the result is obtained by cooling the casting in an air blast. In the range between 4 and 5 per cent of nickel in most castings the rate at which quenching must be carried out in order to obtain martensite corresponds to the speed of cooling in the foundry. It will thus be realized that the use of the alloy iron greatly facilitates heat treatment in that it

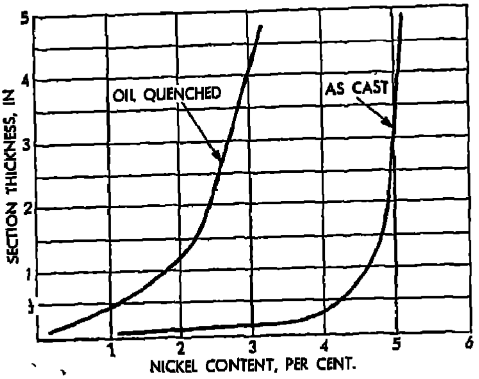


Fig. 2.2. *Nickel content required for satisfactory hardening in various sections.*

enables it to be applied to castings of such complex nature that they would not normally withstand the more drastic forms of quenching. Whilst by slowing up the speed of cooling the heavier sections can be heat-treated successfully, at the same time giving a more uniform result. These points are emphasized in Fig. 2.2, which shows the nickel content required for satisfactory hardening in various sections. It will be seen that whilst it would be very difficult to produce a high level of hardness in heavy sections without nickel, this can be achieved by oil quenching when nickel is present, the required amount increasing with the section thickness. In heavy sections, also owing to the response achieved with nickel, a higher level of hardness can be obtained. This is shown in Fig. 2.3, which also illustrates the point that with the alloy iron uniformity of hardness across the heavy section is obtained.

Heat treatment by quenching and tempering is applied to castings where a combination of hardness and strength is required, thus ensuring wear resistance in parts such as valve guides, cams, gears, and so on. Fig. 2.4 shows curves for hardness and strength in alloy cast iron subjected to the quenching and tempering treatment. It is seen that on oil quenching the casting from, say, 850 deg. C., a marked increase in hardness is immediately achieved, but the strength of the metal falls because

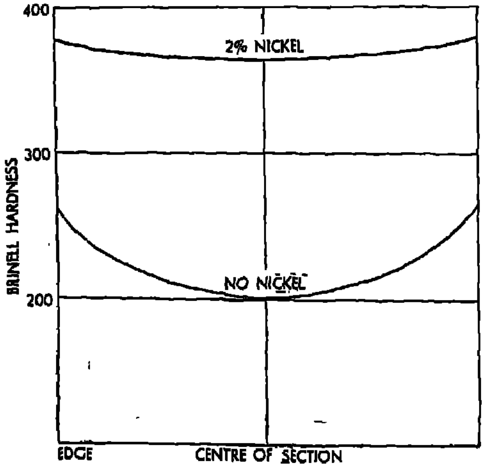


Fig. 2.3. *Showing the effect of oil-quenching heavy sections in plain and nickel cast irons.*

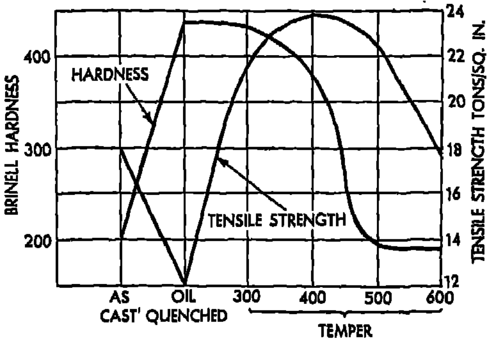


FIG. 2.4. *Showing the effect of heat treatment on the strength and hardness of alloy cast iron.*

of internal quenching stresses. Tempering is, in effect, a rapid form of stress relief annealing. At a temperature about 300 deg. C. the strength of the casting is not only restored, but is even raised above the level originally shown in the metal. At higher temperatures there is an even further increase in strength, but hardness gradually falls until at a temperature of 500 deg. C. it has dropped to the level shown by the original metal. The strength, however, is still appreciably above the original, so that by careful selection of the tempering temperature, various combinations, such as high hardness with high strength, or hardness with intermediate strength, or alternatively, low hardness with a tensile strength still appreciably above that of the original metal can be developed.

FLAME HARDENING

A special quenching and tempering process now extensively practised in industry for the localized hardening of iron castings, is flame hardening. This is applied to gears, cams, lathe beds, and other machine-tool and general engineering castings in which hard-wearing surfaces combined with a tough, strong machinable base are required. Localized hardening is achieved by the use of special equipment in which gas torches heat the surface to be hardened, this being quenched immediately by water jets. The whole process is mechanized so that the flame and water jets travel over the surface of the part to be surface-hardened. Electric induction heating may similarly be used.

HEAT TREATMENT OF S.G. IRON

The development of spheroidal graphite cast iron has provided the engineer with a new range of iron castings. The spheroidal form of the graphite allows the fuller realization of the properties of the steel-like matrix in the castings. The majority of S.G. iron castings, except perhaps many of the larger sizes, are delivered after some form of heat treatment in the foundry. All the normal types of heat treatment applied to iron and

TABLE 2.4
TYPICAL PROPERTIES OF HEAT-TREATED SPHEROIDAL GRAPHITE IRON

Type	*Treatment*	*Tensile Stress t.s.i.*	*0·5 per cent Proof Stress t.s.i.*	*Elongation %*	*Brinell Hardness*	*Impact Izod 10 mm² notched ft.—lb.*
S.G. Iron containing about 1% Ni. As cast		35·0–44·5	25·5–35·0	1–3	220–280	1–2
Stress-relieved	2 hrs. at 550° C.	38·0–47·5	25·5–35·0	3–5	220–270	2
Normalized	2 hrs. at 850° C. air cool	44·5–57·0	32·0–44·5	3–7	240–300	5
Quenched and tempered	Quenched from 850° C. Tempered at 350° C.	57·0–66·5	47·5–60·5	1	450–525	1
	Quenched from 850° C. Tempered at 500° C.	60·5–70·0	51·0–60·5	1–3	350–450	3
	Quenched from 850° C. Tempered at 600° C.	47·5–57·0	38·0–47·5	3–5	250–325	6
Flame-hardened	Surface hardened				600–750	
Annealed	2–4 hrs. at 850° C.–900° C. 6–12 hrs. at 700° C.	25·5–30·5	17·0–22·5	12–25	140–180	7–14

steel castings are used, but the two most important types of heat treatment for S.G. iron are first, full annealing to the ferritic state, and secondly, normalizing.

Full annealing of S.G. iron castings to the fully ferritic structure is generally necessary to meet Type 2 in B.S. 2,789 (see Table 1.6). To obtain the best ductility and impact strength in the castings, they are generally annealed for two to four hours at a temperature of 850 to 900 deg. C. and then are cooled to about 700 deg. C. and held for a period of six to twelve hours according to the size of the casting. Details of this and other heat treatments applied to S.G. iron are indicated in Table 2.4, together with a summary of the properties developed. Annealing is generally carried out in electrical, gas- or oil-fired furnaces, and in many foundries modern programme-controlled furnaces are now in use. In addition, to avoid excessive scaling either a neutral atmosphere is used or the castings are packed in containers. In all cases care must be taken to see that the castings are suitably supported to avoid sagging or warping during annealing.

Normalizing by heating for two hours at a temperature of 850 deg. C., followed by rapid cooling is widely used to develop high strength and wear resistance in S.G. iron castings. The matrix is predominantly pearlitic. After heating at the normalizing temperature, the castings are withdrawn from the furnace and either allowed to cool in the air or in an air blast. This treatment is used for such parts as crankshafts, gears, cams, dies and tools, etc. where a combination of maximum strength with reasonable shock resistance together with good wear resistance is required. Sometimes further improvement is given by a tempering treatment after normalizing. The figures in Table 2.4 emphasize the outstandingly high properties developed in this type of iron casting.

Table 2.4 shows properties of S.G. iron in castings after other more conventional forms of heat treatment (such as stress relieving, quenching and tempering) and after surface hardening. It will be noted that in the latter treatment a hardness of up to 750 D.P.N. can be developed. Other properties are, of course, not quoted since these vary across the section. It should be emphasized with regard to the surface hardening that the castings should initially have a matrix with sufficient combined carbon present to ensure response to the treatment. For this reason the surface hardening of fully annealed ferritic S.G. iron is only effective when a double treatment is used, the first being calculated to raise the combined carbon content in the surface layers of the casting.

All the properties shown in Table 2.4 can be further modified by alloying the S.G. iron, e.g. with higher nickel content, with molybdenum, etc. Alloy grades of S.G. iron include the acicular S.G. iron and the austenitic types. Once again, these irons are often given some form of heat treatment at least for the relief of internal stress.

HEAT TREATMENT OF STEEL CASTINGS

It is advisable that all steel castings be given some form of heat treatment, with the possible exception of some low carbon castings, subject only to non-exacting conditions of service.

The main objects of the heat treatment of steel castings are:

(1) Breaking down or refinement of the relatively coarse structure of the cast metal;

(2) Relief of internal stresses;

(3) Development of desired physical properties.

The most suitable heat treatment depends on the composition, shape, and service requirements of the casting. The equipment must provide facilities for controlled heating and accurate maintenance of the casting (or load of castings) at a suitable temperature. This temperature will depend mainly on the carbon content, but may be modified by the presence of alloying elements.

The principles of heat treatment are derived from studies summarized in the iron—iron carbide equilibrium diagram. Reference is made to the critical range, which lies, as already explained, above 720 deg. C. In this range the iron dissolves iron carbide, forming the solid solution—austenite. The metal forms a fresh, finely crystalline structure and a general diffusion and levelling out of local heterogeneity commences. This is completed at a temperature depending on the carbon content. This upper temperature decreases fairly uniformly from about 900 deg. C. for very low carbon steels to 720 deg. at 0·83 per cent carbon. This range in temperature—the critical range—has a fixed lower point (720 deg. C.) and varies from 180 deg. C. to zero in extent. Above 0·83 per cent carbon the upper temperature rises again rapidly. These temperatures may be varied appreciably by the presence of elements other than iron and carbon. Heating is carried above this range for uniformity.

The principal forms of heat treatment may be classified as follows, and their effects are illustrated in the case of a 0·3 per cent carbon steel (Figs. 1.22–25).

(1) *Annealing*. This consists in heating above the critical range, followed by slow cooling, usually in the furnace, either to about 600 deg. C. and then air cooling; or to room temperature, while held in the furnace.

This treatment gives the most complete relief of stresses, minimum yield and ultimate stress, good ductility and poor impact values. It also produces the best magnetic properties in low carbon castings.

(2) *Normalizing*. Consisting in heating through the critical range, followed by air cooling. The rate of cooling may be retarded by cooling on a bogie, or in a pile; or accelerated by using an air blast if required. Normalizing gives good yield and ultimate stress; ductility only slightly lower than annealing, and good impact values.

(3) *Quenching and Tempering*—i.e., quenching in oil or water from above the critical range followed by reheating to an appropriate temperature below the critical range. It is advisable to anneal, or normalize, before heating for quenching. This treatment gives optimum physical properties but is usually difficult in application to castings unless they are of simple shape.

(4) *Stress Relief Treatment*—i.e., heating to 600-650 deg. C. and cooling slowly. This is applied to eliminate stress resulting from previous heat treatment or heavy machining.

The great majority of castings are annealed or normalized, the choice of treatment depending on the casting and the physical requirements. Quenching and tempering can be applied with advantage to suitable carbon steel castings but is more frequently used with alloyed steel castings. The coarse crystalline structure of cast steel is not readily broken down by heat treatment alone, and a higher temperature and a much longer time is required than when dealing with material that has been forged, or whose structure has been otherwise mechanically broken up. Annealing, or normalizing, requires much the same soaking temperature, ranging from about 950 deg. C. for low carbon to 860 deg. C. for high carbon steels. A minimum period of two hours is advisable with further time for thick sections, based on the approximate rule of one hour per inch of section. Heating to temperature should be as uniform as possible and not too rapid; due care must be taken to ensure that the temperature of the castings is fairly represented by the thermo-couple readings.

A higher temperature permits much shorter soaking time, but may lead to grain growth and deterioration of ductility and impact values. By normalizing first from a high temperature and then reheating just above the critical range followed by air cooling, a maximum refinement of grain and excellent properties are obtained. Another popular variation is to normalize as usual and then temper at 550-700 deg. C., this giving some reduction in yield but much better ductility in the higher strength castings. It is possible to combine this double normalizing treatment with a third tempering treatment in order to obtain maximum properties without quenching. If quenching is carried out the quench should be made less severe, if possible, by using oil or warm water; the castings should be removed from the quench while warm and reheated to tempering temperature as soon as possible.

Reference should be made to Table 1.7 for details of some of the heat treatments recommended for special types of steel produced in modern steel foundry practice.

HEAT TREATMENT IN THE NON-FERROUS FOUNDRY

Generally speaking, heat treatment is not carried out in the non-ferrous foundry to anything like the same degree as in the case of steel and cast iron. The reason for this is not difficult to find since, as already explained, in the latter industries a great deal of heat treatment is rendered necessary by the development of undesirable structures at high temperatures, and by the incidence of casting stresses. Dealing with the latter first, it has already been mentioned that the extent to which stresses develop in a casting is determined primarily by the length of the temperature range through which the casting passes during cooling. Most of the non-ferrous metals encountered in the foundry have a much lower solidification temperature than is the case with iron and steel. Consequently, the cooling temperature range is proportionately less, and the cause of the development of casting stresses is thus diminished.

Of great importance, however, is the fact that most of the non-ferrous metals are more ductile than is cast iron, especially at elevated temperatures, though generally to a lesser extent than are the steels. Being more ductile, the castings are more rapidly able to adjust themselves to casting stresses, and such stresses are, therefore, automatically relieved. For these reasons it can be stated that stress relief of non-ferrous castings is rarely if ever carried out. A further point is that even if residual stress is present in a casting, it is less likely to lead to sudden failure through shock in more ductile material than in brittle metal like cast iron. Consequently, less attention is necessary to this feature in the case of non-ferrous castings. The other main reason for the heat treatment of iron and steel, it will be recalled, is to control the structure of the metal, thereby modifying the nature of the metal matrix, generally bringing about a reduction in grain size; or alternatively by modifying the structure of the metal through control by heat treatment of the various constitutional changes through which the metal passes on cooling.

It is not true to say that the non-ferrous metals are in any way simpler from the constitutional point of view than cast iron or steel. In fact, those metallurgists who are concerned with the so-called constitutional diagrams of the non-ferrous alloys will realize that the bulk of these materials are far more complex in their structure than are the ferrous metals. From the general point of view, however, the structure of foundry non-ferrous alloys is less amenable to heat treatment, and only in special cases is any heat treatment carried out as for iron and steel.

PRECIPITATION HARDENING

A special type of heat treatment applied to non-ferrous castings which has become of very great importance in recent years is precipitation hardening. When, during the First World War, certain types of aluminium alloys were developed for aircraft construction, it was found that such alloys as, for example, "Duralumin," gradually changed their properties with time. Thus, rolled bars of these alloys, when checked and put into stores, were found to have materially altered in respect of hardness, strength, and other characteristics when taken from stores some time later. This ageing effect is now known to be due to precipitation hardening. Initially, it was little understood apart from recognizing that the alloy was fundamentally unstable.

In the intervening years, it has been realized that precipitation hardening, bringing about this change of properties, is tied up with certain gradual constitutional changes in the metal. It is due to the rejection from the body of the metal of certain constituents which are present in a supersaturated form. As we know, many metals will absorb a second metal, or alternatively, one constituent of the metal may absorb a second constituent having a solubility which varies with temperature in the solid state. In such cases, the metal may be stable at high temperatures, although near the solubility limit of the second constituent. As the temperature falls, however, the solubility in respect of the second constituent will decrease. If the metal is cooled slowly, then the second constituent will separate out from the parent metal during cooling. If, however, the metal be cooled rapidly, then it is probable that some of the second constituent will be retained in a state of supersaturation.

This is the state of affairs leading to the change of properties in "Duralumin." It is found in both ferrous and non-ferrous alloys, and especially those in the light castings industry. Properly controlled, this type of constitution is a useful tool in the hands of the metallurgist and offers valuable properties to the engineer, since, in the state of supersaturation, the alloys may be workable and tough, whilst if the second constituent is precipitated under controlled conditions, the hardness, strength and mechanical properties generally of the metal may be greatly improved. Incidentally, a very interesting example of this phenomenon is found in some of the new magnet steels, such as "Alnico," containing nickel, aluminium and cobalt. In such steels, the precipitation of the compounds of nickel and aluminium at high temperatures, results in the development of intense mechanical hardness, with, at the same time, magnetic properties depending on such precipitation which give some of the best magnets known today.

In the modern foundry supplying, for example, light castings to the

TABLE 2.5

TYPICAL PROPERTIES OF A HEAT-TREATABLE CAST BRONZE

(Cu 88 Ni 5 Sn 5 Zn 2)

Treatment	*Max. Stress t.s.i.*	*Proof Stress* 0·1 *per cent t.s.i.*	*Elongation per cent*	*Brinell Hardness Number*
As sand cast	22·0	8·0	35·0	85
Heated at 350° C. for 5 hours	29·0	—	10·0	130
Heated 5 hours at 760° C., cooled in furnace to 550° C., and water-quenched. Reheated 5 hours at 350° C., and water-quenched.	38·0	24·0	5·0	180

aircraft industry, precipitation hardening is employed regularly in order to develop the maximum possible properties in the castings. The treatment is applied, in addition, to many of the light alloys, to certain special types of brasses and bronzes, to some of the copper and nickel alloys, and to other non-ferrous foundry products. The usual procedure is to apply a fast cooling rate to the castings and to reheat them to some intermediate temperature when precipitation of the insoluble constituent takes place in a finely divided form in the body of the metal. When precipitation is complete, the castings are cooled to room temperature and are ready for service. This treatment is, in effect, a speeding up of the ageing noted in the case of "Duralumin".

An example of the improvement in mechanical properties brought about by precipitation hardening in the case of a non-ferrous casting alloy is illustrated in Table 2.5. Substantial improvements in the strength and wear resistance are seen to result from heat treatment. This is a typical case and represents several others on non-ferrous alloys used for valve and pump parts, yokes, marine castings, agitators, gears and bearing sleeves, etc.

CONCLUSION

In view of the general nature of this book reference has been made only to the more common types of heat treatment likely to be met in the foundry. Many more specialized types of heat treatment are carried out on foundry products in the foundry as well as in machine shops and engineering works generally. These, however, fall outside the scope of the present work. Many other types of heat treatment are required for stabilizing

TABLE 2.6

SOME COMMON METALLURGICAL ABBREVIATIONS

Abbreviation	*Explanation*	*Abbreviation*	*Explanation*
AC	As cast	OH	Oil hardened
AH	Air hardened	P	Phosphorus
C	Carbon	R of A	Reduction of area
Cr	Chromium	S	Sulphur
El	Elongation	Si	Silicon
Mn	Manganese	T	Tempered
Mo	Molybdenum	W	Tungsten
MS	Maximum stress	WQ	Water quenched
Ni	Nickel	YP	Yield point

castings when they are subjected to welding processes as, for example, in the fabrication of large structures. This again, however, falls outside the scope under review. As hinted above, many types of special alloy steels and non-ferrous metals respond to specialized types of heat treatment. The whole field is vast, but the information given above will be sufficient to illustrate the broad principles under which heat treatment is carried out in modern foundry practice.

Table 2.6 may be found useful by readers unfamiliar with the abbreviations commonly adopted in this field, and used elsewhere in this book—in particular, in Table 1.7, pages 60–61.

Chapter 3

NON-FERROUS ALLOYS

PRIMITIVE copper and bronze implements were in use at least five thousand years ago, while bronze and brass compositions which were mentioned in Biblical times have continued to be used down the ages to the present day. It is, however, only since the beginning of the twentieth century that aluminium, nickel, magnesium and more recently titanium, beryllium, cerium, cobalt and chromium have become commercially available, and new alloys with these metals as the base (or alloys containing them) have come into commercial use. The increased demand for light-alloy castings, following the rapid development of the motor car and the even more spectacular development of flying, has been responsible for the rapid growth in amount and importance of light-alloy founding. Light alloys require their own special technique which had to be devoloped, and efficient and low scrap-level casting production has become possible within the last thirty years only because this new branch of founding has been intensively studied and developed.

Many of the smaller non-ferrous foundries must produce both bronze and light-alloy castings in the same foundry, and where this is the case it is necessary to segregate correctly all scrap and splashings, particularly as contamination of tin bronzes with quite small amounts of aluminium is sufficient to cause loss of strength and leakage under pressure, and to result in a high scrap level. The tin bronzes are the most commonly used alloys and are cast in the greatest tonnage, although a considerable tonnage of brass is now also cast. Special alloys such as the aluminium bronzes and brasses, high-tensile brasses and nickel alloys are not so easy to cast, requiring more attention and careful treatment as regards moulding, melting, pouring temperature, running and feeding.

The non-ferrous foundryman who has to produce iron castings will find that his moulding, running and risering experience is adequate; but the change from iron founding to non-ferrous founding is not so readily accomplished. Because of the greater strength but much higher metal cost, non-ferrous castings are usually designed with thinner sections than those of corresponding iron castings, and this necessitates good pattern and core-box equipment and greater care in moulding, together with knowledge and experience of the best methods of running and feeding, taking into account the characteristics of the particular alloy being cast.

COPPER-BASE NON-FERROUS SPECIFICATIONS

British Standard Specification 1,400: 1948, "Copper alloy ingots and castings," covers a range of copper-base non-ferrous alloys normally adequate to meet the needs of general engineering. These alloys were derived from, and mostly previously covered by, War Emergency Specifications which were drawn up by the industry during the Second World War. B.S. Specification 1,400: 1948 is at present (1958) under revision, but it is not anticipated that major changes will be made. The alloys at present specified comprise two gunmetals, G1-C and G2-C; three leaded gunmetals, LG1-C, LG2-C and LG3-C; three leaded bronzes, LB1-C, LB2-C, LB3-C; three phosphor bronzes, PB1-C, PB2-C, PB3-C; and one leaded phosphor bronze, LPB1-C. There are six brass compositions, B1-C, B2-C, B3-C, B4-C, B5-C and B6-C; two aluminium bronzes, AB1-C, AB2-C; one silicon bronze, SB1-C; and three high-tensile brasses, HTB1-C, HTB2-C and HTB3-C.

This range of specified compositions has done much to rationalize the considerable number of non-ferrous alloys previously demanded by various ordering bodies, many of whom had issued their own varying specifications. The B.S. Specification also embodies clauses which cover the provision of a test certificate, chemical tests, moulding, freedom from defects, pouring and test samples, mechanical and pressure tests; an appendix covers the dimensions of test pieces.

The most widely used alloy is 85/5/5/5 (LG2-C). The specification allows a range of from 4 to 6 per cent tin; 4 to 6 per cent zinc; 4 to 6 per cent lead, with up to 1 per cent maximum nickel, total of other elements 0·5 per cent, and the remainder copper. Not much 88/10/2 Admiralty gunmetal is now cast, as this has largely been replaced by 86/7/5/2 (LG3-C). This alloy of 86 per cent copper, 7 per cent tin, 5 per cent zinc, 2 per cent lead, which is a higher grade and higher strength alloy than LG2-C, is probably next in total tonnage cast. A considerable tonnage of brass is also cast for constructional castings which are comparatively lightly stressed and are not subjected to temperatures much above normal under working conditions. Lead improves the bearing properties and machinability of these alloys. Little difference is made in foundry treatment apart from a certain amount of extra feeding where necessary and the lower casting temperature.

COPPER-TIN EQUILIBRIUM DIAGRAM

Equilibrium diagrams would seem to have little connexion with the foundry; nevertheless, the main features of the alloys in use should be appreciated. Alloys are rarely straight compositions of two metals only, and even where they are, the two metals are not usually pure. Most

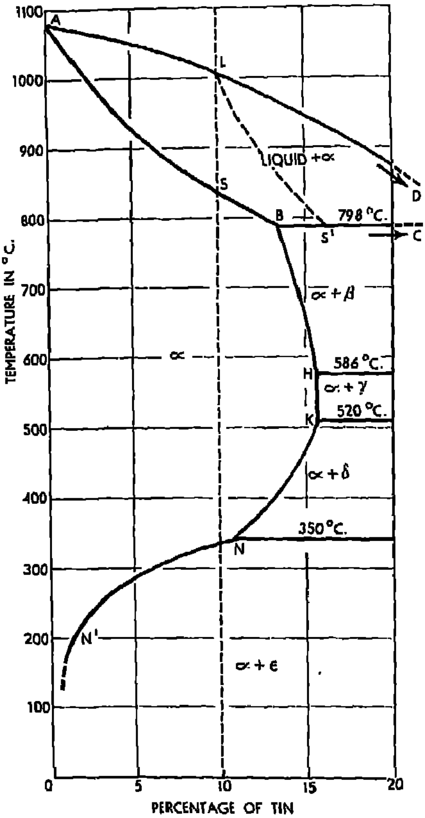


Fig. 3.1. *Copper-rich portion of the system copper-tin, from "Equilibrium Diagrams of Binary Copper Alloys" (Copper Development Association). From the Institute of Metals annotated equilibrium series No. 2, prepared by Prof. G. V. Raynor.*

commonly used non-ferrous alloys consist of combinations of copper, tin, lead, zinc, aluminium and nickel, but fall broadly into the classification of brasses or bronzes—bronze being mainly copper and tin, and brass being mainly copper and zinc.

Apart from the fact that no alloy is entirely copper and tin or copper and zinc, the comparatively rapid solidification following the filling of the mould prevents equilibrium conditions being reached, so that although much can be learned from the equilibrium diagram, it must always be remembered that foundry alloys are not simple binary compositions, and that the rate of solidification produces results which are not immediately apparent from a study of the equilibrium diagram.

Fig. 3.1 reproduces the copper-rich end of the copper-tin equilibrium diagram. The diagram looks deceptively simple so far as the alloys containing up to 20 per cent tin are concerned, which is all that the average foundry is likely to have to deal with. The line AD represents the liquidus, the temperature at which solidification commences. Taking, for example, a 10 per cent tin bronze, freezing commences at approximately 1,010 deg. C. The line ABC represents the solidus (the completion of solidification) which for a 10 per cent tin bronze under equilibrium conditions is completed at about 840 deg. C.

According to the diagram, a straight 10 per cent tin bronze solidifies with the formation of the α solid solution, and solidification is complete

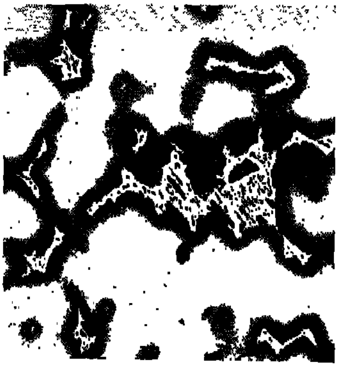


FIG. 3.2. $\alpha + \delta$ *eutectoid in gunmetal.* × *100.*

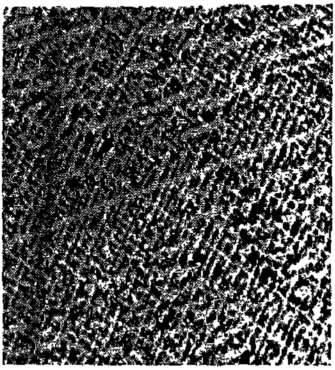


FIG. 3.3. *Gunmetal* × *25 etched, showing the marked dendritic structure of rapidly cooled alloy having good mechanical properties.*

at 840 deg. C. Under practical foundry conditions, however, it is not quite like this. The final as-cast structure of correctly cast bronze will be found to show a strongly dendritic arrangement of cored and non-uniform composition, in which occurs (according to casting conditions) varying amount of $\alpha + \delta$ eutectoid (Fig. 3.2), and where solidification is not complete until a temperature of 795 deg. C. is reached.

If $\alpha + \delta$ eutectoid is present, solidification must take place not as represented by the dotted vertical line LS in Fig. 3.1, but rather by a curved line LS^1, displaced to the right somewhat as shown. The reason for this—which also accounts for the cored dendritic structure usually found (illustrated in Fig. 3.3)—is primarily the extended freezing range, and the very slow rate at which diffusion occurs in solid bronze, coupled with the large amount of diffusion necessary to reach equilibrium as required by the equilibrium diagram.

As the α solid solution may hold up to 16 per cent tin, it might be thought that the material first solidifying in a 10 per cent tin-bronze would be a uniform solid solution of tin in copper, but owing to the wide freezing range, a horizontal line, extending to the left from the point L until it reaches the solidus line AB, indicates that the first-formed dendrites contain approximately only 2 per cent tin. The effect is to produce concentration of tin in the still-liquid portion, and as the cooling and solidification proceed this concentration increases. The solid deposited around the dendrites becomes gradually richer in tin, but is always below the level of the still-increasing tin content in the liquid portion. Eventually, a point S^1 is reached at 798 deg. C., when the small remaining portion of liquid, having reached a concentration of over 13 per cent tin, finally solidifies completely. The alloy then consists of the α and β constituents. Intermediate changes occur at 586 deg. C. and at 520 deg. C., when there is a breakdown to α and δ, and the amount of α + δ eutectoid in the final structure will be determined by the position of the displaced terminal solidification composition on the solidus BC. The solidification terminal point, and the resulting amount of α + δ eutectoid, will vary according to the casting conditions.

In an actual casting, the δ eutectoid, including its amount, shape and distribution is of practical importance (Fig. 3.4). The δ eutectoid is a hard and comparatively brittle constituent, having a Brinell figure of over 200; consequently the strength, hardness and ductility of the alloy in which it occurs depend upon the amount present and the way in which it is distributed. The amount present is primarily dependent on the tin content of the alloy, but is also influenced by the pouring temperature and rate of solidification. Both zinc and phosphorus also increase δ formation, and it is usually accepted that zinc is equivalent to half its amount of tin; thus an 88/8/4 alloy structurally resembles a 90/10 straight tin bronze. Apart from composition, the amount of the δ eutectoid is affected by the rate of cooling. This depends upon the casting temperature and the section and mass of the casting under consideration. Normally, only the casting temperature can be varied, and this only within certain limits. The only other variable factor would be more rapid solidification, which can be achieved either by the use of chills or by the use of moulding materials other than sand.

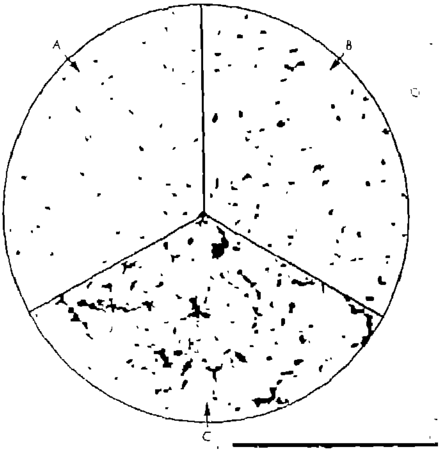


FIG. 3.4. *Varying amounts of α + δ eutectoid in three different specimens of gunmetal.* × 25.

THERMAL PROPERTIES OF MOULDING MATERIALS

The thermal properties of moulding materials have been investigated by F. Hudson and others, and various sands have been found to have relatively uniform but quite low thermal conductivity. Low thermal conductivity results in a build-up of temperature at the mould face. The higher the metal temperature, therefore, the higher the initial mould-face temperature, and as the heat transfer from the mould face through the backing sand is slow, a high casting temperature results in considerably slower cooling during the solidification period, so that the final structure is directly affected by the casting temperature. These investigations also deal with the thermal properties of possible moulding materials other than sand. Hudson found that carborundum sand could be successfully used, giving a high thermal conductivity approximating a metal chill. The usefulness of this should be appreciated by all foundrymen, as it offers a means of chilling and speeding the rate of solidification of heavy casting sections. Metal shot or grit can be bonded and used, or mixtures of metal grit and sand are also effective.

R. F. Hudson has described how difficult castings with heavy bosses, or gear wheels whose teeth have to be machined sound and with a dense, hard-wearing structure, can be greatly improved by the use of a rapidly conducting carborundum sand mixture. A typical mixture consists of approximately 85 to 87 per cent suitably graded carborundum with 5 to 7 per cent Bentonil or Fulbond, 1 per cent molasses, and a water content of about 7 per cent. Carborundum sand mixtures can also be bonded with an oil/cereal, or a semi-solid core compound, or with silicate bonds for use with the CO_2 process. Comparisons of test bars cast in such mixtures with bars cast in ordinary sand show considerable improvement in mechanical properties.

Treating the matter from a practical foundry point of view and under foundry conditions, Dews has given a solubility figure for tin in the α solid solution as 7 per cent, while Lepp places it as high as 14 per cent in metal which has been degassed. Much depends upon the initial tin content, the solidification rate, the amount of gas present and other factors. A feature which has been noted is that the solubility of tin in the α solid solution, judged by the amount of $\alpha + \delta$ eutectoid formed, appears to be connected with factors associated with the melting conditions. One such factor may be the effect due to the presence of gas, as appears from the work of Lepp, who has shown that a degassed bronze can contain up to 14 per cent tin in solid solution under industrial conditions without δ formation, and such bronzes give enhanced mechanical properties with considerably increased ductility.

On the other hand, an abnormal amount of $\alpha + \delta$ eutectoid has been

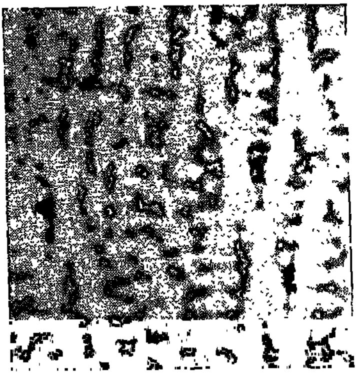


FIG. 3.5. *Arrangement of* $\alpha + \delta$ *eutectoid in gunmetal relative to the coring and porosity voids.* × *100.*

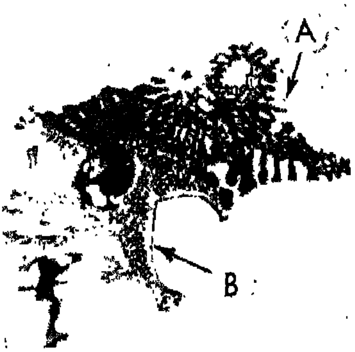


FIG. 3.6. $\alpha + \delta$ *eutectoid (B) and associated copper phosphide (A) in phosphor bronze.* × *650.*

noted as associated with the presence of undue amounts of oxide films, indicating oxidized metal.

STRUCTURE OF BRONZE

Cast gunmetal of good quality usually exhibits a strongly dendritic arrangement as in Fig. 3.3, which illustrates the structure (after etching, and at a magnification of 25 diameters) of material of over 21 tons per sq. in. tensile strength and approximately 37 per cent elongation. Spaced throughout such a structure are areas of $\alpha + \delta$ eutectoid, porosity voids ranging from micro to macro in size, and lakes of lead when lead is present. The importance of the $\alpha + \delta$ eutectoid has been mentioned, and varying amounts will be found according to the composition, casting temperature, and solidification rate as shown in Fig. 3.4. Section A represents the amount of δ eutectoid in the strong gunmetal shown in Fig. 3.3, while Section C is the larger amount associated with poor gunmetal of low strength and ductility.

The presence of the $\alpha + \delta$ eutectoid in quantity is desirable where the alloy is to provide a bearing surface. In this respect, material C is superior to material A, although vastly inferior in physical properties. Fig. 3.5 shows a typical arrangement of the $\alpha + \delta$ eutectoid constituent with coring and porosity voids. The presence of large amounts of $\alpha + \delta$ eutectoid, with the additional hard constituent copper phosphide (Cu_3P) which is associated with the δ constituent when it is present as in Fig. 3.6, is purposely sought for bearing purposes, and is achieved by the use of alloys with larger amount of tin, and by the inclusion of a definite percentage of phosphorus in the composition which then becomes a phosphor bronze.

The structure of an average-strength gunmetal (see Fig. 3.5—magnified by 100 diameters) shows the $\alpha + \delta$ eutectoid and voids in relation to the dendritic arrangement. Porosity is always present to a certain extent, and it seems to be impossible to produce commercial gunmetal castings which are free from a small amount of micro-porosity, consequently soundness is entirely a matter of degree.

MELTING FURNACES

Melting furnaces in the brass foundry are usually of the following types: coke or gas fired pit furnace; coke, gas or oil fired tilting furnace; open-hearth reverberatory furnace; oil or gas fired direct-flame furnace of static or semi-rotary type; electric-arc furnace and electric induction furnace. Non-ferrous melting furnaces have changed little in design over many years, but new types with special advantages have appeared recently. One is a fully automatic electric die-casting furnace which can be set to switch itself on at the correct time so that the metal will be ready for the casters when they arrive. It switches itself off at the end of the day, and this is more economical than maintaining the metal molten overnight. The solidification of the metal in the crucible and its subsequent re-melting does not crack the crucible and avoids the necessity for emptying and recharging, thus saving unnecessary labour. Another new furnace is the mains-frequency coreless induction furnace. This is a crucible-type melting-chamber furnace which requires no frequency-conversion equipment, thus materially lowering the initial cost. It is being made in all sizes up to 15 tons capacity.

Furnaces can be considered as being of two main types: those which allow protection of the metal while melting, and those where the metal has no protection and is in direct contact with the flame and products of combustion. The first type covers furnaces which melt the charge in crucibles, and the second includes all forms of reverberatory and oil- or gas-fired semi-rotary furnaces. This distinction should be kept in mind, as it is important from several points of view, particularly that of melting loss. This aspect must be given full consideration because of the high cost of present-day non-ferrous alloys. The major considerations in furnace installation are speed of melting, fuel efficiency, labour and upkeep charges for both working and maintenance, ease of working, metal loss when melting, and quality of the resultant melt. It will be noted that first cost is not included, as this may be misleading in relation to efficiency and metal loss, and therefore to the ultimate economy.

A particular type of furnace may be best adapted to deal with the conditions in a given foundry, but there is no universal "best" furnace. The coke-fired pit furnace is still widely used because of its low first cost and simplicity, although these factors are outweighed by low efficiency. However, it will produce metal of excellent quality, with low metal loss because of the protection afforded by crucibles, and presumably will continue to be used for a long time yet. Pit-fired crucible furnaces are often built side by side, with the flues leading into one common flue connecting with a high chimney. The rate of melting depends upon the draught available, but the time of melting can be stabilized and shortened by enclosing the ash-pit space and supplying forced draught.

If gas can be obtained at a reasonable price, it may be worth considering the conversion of such a battery of pit furnaces to gas melting, advantages being that little labour is required for furnace maintenance, and none for cleaning or stoking. Coke-storage space is saved and the necessity for coke drying is eliminated. A mixture of gas and air can, with experience, be visually adjusted to give the best thermal efficiency with correct, slightly oxidizing conditions. Melting is rapid, and what is equally important is that the time of melting is known with certainty, so that a melting programme can be arranged and adhered to. A disadvantage is that crucibles do not glaze so well, and pot life may thereby be reduced, but this is compensated by other material and economic gains.

Gas-fired furnaces are particularly easy to operate and control, and gas firing has some advantages over oil although the fuel cost per B.T.U. is higher. Compared with lining costs for the semi-rotary or reverberatory type furnace, crucible costs will be higher, but as the cost of metal is high and metal loss can be low, the result is that the final advantage will, surprisingly enough, often be with crucible melting. The semi-rotary or reverberatory, direct-flame type of furnace has an advantage in speedy melting, where this is important. With modern furnaces and knowledge of melting conditions there need be no difference in metal quality, although greater care in the adjustment of burner settings may be necessary if metal loss is to be maintained at a low level.

FURNACE ATMOSPHERES

Furnaces, particularly if gas or oil fired, can be adjusted to give either a reducing atmosphere (rich in fuel and deficient in air), an oxidizing atmosphere (low in fuel and having excess air), or a neutral atmosphere which is neither reducing nor oxidizing. At one time, the opinion was prevalent that melting should be carried out in a reducing atmosphere and that oxidizing conditions were to be avoided. It is true that non-ferrous alloys can be oxidized to such an extent as to be rendered almost uncastable, but it is now well known that a slightly oxidizing atmosphere is advantageous, and that a reducing atmosphere results in gassed metal.

The best way to determine the state of the furnace atmosphere while melting is to carry out an analysis of the flue gas. Facilities for gas analysis are not usually available in the smaller foundries, and a good practical method of assessing the condition of the furnace atmosphere is to take a clean stick or rod of pure zinc, and expose it to the flame in the exhaust flue. The test depends upon the different colours the zinc rod assumes when affected by the atmosphere of the flame for a period of from a quarter to half a minute. The colours range from black to brown, gold, and straw under reducing conditions; changing to no colour or a slight grey under an oxidizing condition. The zinc rod should have a clean, metallic surface freshly prepared by wire brushing, emerying and filing, and the indications shown in Table 3.1 can then be reliably assumed.

TABLE 3.1
ZINC ROD TEST FOR FURNACE ATMOSPHERE

Colour	*Indication*
Lamp-black deposit	Very reducing atmosphere
Black to golden	Reducing atmosphere
Golden to yellow or straw	Reducing atmosphere
Light straw to light yellow	Only slightly reducing
No colour (zinc remains unchanged)	Neutral to slightly oxidizing
Grey to slate	Strongly oxidizing

The zinc test enables the correct ratio of fuel to air to be obtained in order that the proper furnace atmosphere may result.

MELTING LOSS

In a series of melt tests to determine metal loss, carried out by Jackson and Brown, experimental melts were made in LG2 (85/5/5/5) and LG3 (86/7/5/2) leaded gunmetals, also phosphor bronze, brass, and high-tensile brass. The tests were done mainly in a 400-lb. crucible oil-fired central-axis tilting furnace, but some were carried out in a 120 lb. lift-out crucible furnace. As might be expected, it was found that melting losses were mainly due to oxidation, and where no special precautions were taken, the loss amounted to 2½ per cent in the case of brass. A considerable zinc loss occurred if the metal was allowed to boil or flare. The use of charcoal, by providing a reducing atmosphere at the metal surface, reduced loss to about ½ per cent. It should be noted that to obtain consistently sound castings with a charcoal cover, it would be necessary to give a metal-degassing treatment before pouring.

An 85/5/5/5 leaded gunmetal melted without a crucible lid or cover gave losses varying between 1 and 2 per cent. Using charcoal, the loss was approximately 0·4 per cent. With a suitable flux cover which would clean the metal as well as protect it, the metal loss could be lower but certainly not higher, and cleaner and high-quality metal would result. Ajax Wyatt electric induction furnaces are much used for the bulk melting of brass, and melting losses on 70/30 brass have been published showing a figure of 2·3 per cent without a borax cover and 1·3 per cent with a borax cover, very similar figures being obtained with 63/37 brass. With suitable flux covers, metal losses of about 1 per cent are now being regularly achieved even in direct-flame reverberatory furnaces.

The question of metal loss is one which merits the careful consideration of all foundrymen, as frequently high metal loss is accepted as a necessary evil. If carelessness or poor practice results in a 2 per cent metal loss, then taking alloy at an arbitrary price of £170 per ton, this represents a direct loss of £3 8s. on every ton melted, and even where the casting yield (i.e. the weight of fettled castings to the weight of metal poured) is as high as 60 per cent this represents a charge of £5 13s. on every ton of castings made. If a better type of furnace can be installed, or the use of suitable fluxes and better practice generally can be instituted, it should be possible to reduce the melting loss to 0·5 per cent or even lower. This would cut the charge for metal loss to 17s. per ton, or 28s. 4d. per ton of castings—a direct and continuous saving of £4 5s. per ton of castings made.

UNSOUNDNESS

Unsoundness in bronze can arise from many causes. Abnormal amounts of gas may be evolved when casting, either from the use of excessive or unsuitable mould dressing, or from too high a moisture content in the facing sand. Severe metal/mould reaction resulting in gas cavities underneath the casting skin can occur due to reaction with moisture in the facing sand, particularly where the metal has an appreciable phosphorus content, and may be accompanied by an increase in general dispersed porosity.

Considerable work has been carried out and published by the British Non-ferrous Metals Research Association on metal/mould reaction and its effect on mechanical properties and pressure tightness. Phosphorus content between 0·04 and 0·1 per cent in lead-free gunmetal gives improved pressure tightness of sand castings and greater strength in poorly fed sections due to more uniform distribution of porosity. Tests on 85/5/5/5 gunmetal give similar results and show that mould reaction is produced with phosphorus contents between 0·04 and 0·1 per cent, giving decreased strength in well-fed sections but improved pressure tightness in poorly fed sections. Gas absorption due to metal-mould reaction can be inhibited by the use of a mould paint or dressing which consists essentially of finely divided flake aluminium, or an alloy of aluminium and magnesium in a carrier having a suitable bond.

Turbulent entry of metal into a mould, especially with a low casting temperature, may result in entangled air being carried in with the metal into the mould space and becoming trapped in the rapidly solidifying metal. High gas content absorbed during melting results in gas evolution during solidification. If the amount absorbed is small and solidification is rapid enough, the resultant porosity will be microscopic; but if the gas content is high, the subsequent evolution will be large, and cavities will result. Inadequate size or bad positioning of runners and risers, or bad casting design giving extremes of section, may result in inadequate feeding due to failure to compensate for the liquid shrinkage which occurs during solidification. These causes of unsoundness may be diagnosed with experience, although it is difficult and often impossible to distinguish between interdendritic shrinkage unsoundness, and interdendritic gas unsoundness. In many cases, it is certain that porosity from both causes occurs together.

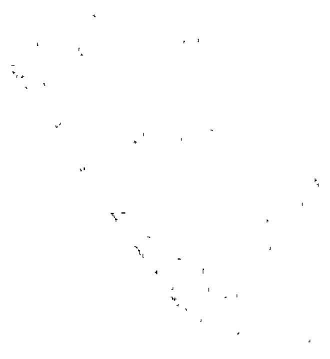


FIG. 3.7. *A section through a "cauliflower riser," showing gas channels through which tin-rich liquid is ejected.*

Trouble in the majority of unsound castings due to the metal is caused by gas. Tin bronzes are peculiarly liable to porosity caused by shrinkage unsoundness because of the long freezing range, coupled with hydrogen evolution. The solubility of hydrogen increases with increase of temperature and decreases as the temperature falls, there being usually a considerable liberation of gas as the last areas of tin-rich alloy between the dendrites solidify. Where excessive gas is present, it will result in a large evolution of gas during solidification, and if bad enough will be responsible for the phenomenon known as "tin sweat" or "cauliflower riser tops." Fig. 3.7 is a section through such a head, and clearly shows the gas channels through which tin-rich liquid is blown out. This particular case was the result of metal having been teemed into a damp casting ladle, the metal having been badly gassed without it being realized at the time.

As regards the freezing range of a 10 per cent bronze, although the equilibrium diagram indicates solidification taking place between 1,010 and 840 deg. C.—a range of 170 deg. C.—yet under foundry conditions, and especially with bronzes containing zinc, the freezing range is even more protracted, being over 200 deg. C.

Mild gas porosity usually manifests itself in a similar manner to shrinkage unsoundness, but when there is a high gas content the amount evolved results in actual voids. In the first case, as already mentioned, the identification and differentiation of shrinkage unsoundness and micro gas porosity may be difficult; but in the second case, the visible cavities which are formed are approximately spherical in shape, and these can be distinguished from gas evolution at the mould face, or from air carried in by the stream of metal entering the mould. Daniels and Bailey have shown that there are two types of gas unsoundness: (1) that due to solution of an elementary gas (hydrogen) with its consequent partial liberation on solidification; (2) that due to the reaction of two constituents in solution, i.e., hydrogen and oxygen in the form of copper oxide present in the alloy reacting to form an insoluble gas (steam) which is then liberated.

Hydrogen in the metal arises from two sources: from the materials of the charge, and from the furnace atmosphere. Scrap charged, therefore, should be clean and dry and as free from oil as possible, and burner settings should be such that a slightly oxidizing condition is maintained. The equilibrium relationship of hydrogen and oxygen in molten copper is shown in Fig. 3.8, from which it will be seen that the solubility of hydrogen is reduced by oxygen. Increasing the temperature increases the amount dissolved but does not affect the general relationship.

Water vapour can be kept to a minimum in the coke-fired furnace by charging only dried coke. Hydrogen is readily formed by passing water vapour through red-hot fuel, but in the presence of free oxygen and carbon dioxide the action is reversible, the hydrogen burning again to form water vapour. Water vapour is not

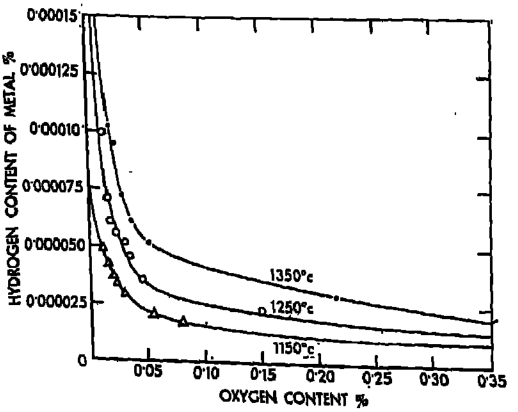


FIG. 3.8. *Oxygen-hydrogen equilibrium in molten copper at different temperatures (Bailey).*

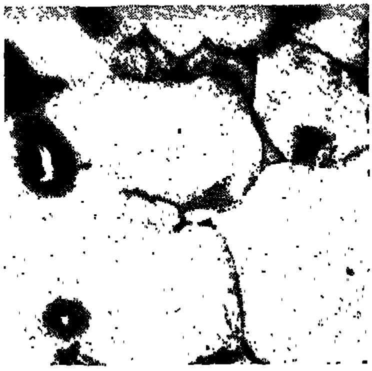


FIG. 3.9. *Oxide films in 85/5/5/5 bronze.* × *250.*

desirable in the furnace atmosphere but free hydrogen is less desirable, and this is one reason for maintaining oxidizing conditions. Another factor is that copper oxide is formed at the surface of the molten metal in an oxidizing atmosphere; and the presence of dissolved oxides, as already indicated, minimizes hydrogen absorption by the molten metal.

On the other hand, an excess of oxygen resulting in considerable amounts of dissolved oxide and entangled oxide films is also harmful. Badly oxidized metal may be sluggish in pouring and feeding, and will certainly have poor mechanical properties and leak under pressure. Oxide films in an 85/5/5/5 bronze are shown in Fig. 3.9. Before pouring all bronze should be suitably deoxidized to reduce and remove oxide films. (Procedure and details are given on page 98.)

Before the factors involved in gas absorption and gas/metal reaction became known, foundrymen established, by trial and error, satisfactory practice and melting conditions for their particular furnaces, and so obtained fairly consistent results. As the furnaces then in use were mainly natural-draught coke-fired pit furnaces with crucible melting, the problem was comparatively simple. The cover used on the metal was almost always charcoal, and in the light of present knowledge it is surprising that badly gassed metal was not more frequent. Metal losses can be low when a charcoal cover is used, and there appears to be a tendency to swing back to the use of charcoal for this reason, but it must be remembered that charcoal does nothing to scavenge or clean the metal in any way.

DEGASSING PROCESSES

Knowledge of gas absorption and gas/metal reactions makes it possible to avoid conditions during melting which produce badly gassed metal, and also to deal with metal which is known or suspected to have become gassed. Knowledge of gas reactions is certainly necessary under present-day conditions when alloys which are prone to gas absorption are being increasingly used, and when direct-flame melting furnaces are used to a greater extent because of their fast melting rates and fuel economy. From a foundry point of view, the essential thing is to prevent or minimize hydrogen absorption by correct melting practice in the first place, and this should be standardized and adhered to.

Melting in crucibles should be carried out under slightly oxidizing conditions, using dry coke where this is the fuel and dried charcoal if charcoal is used as a cover. Better protection is afforded by proprietary liquid flux covers, and these are often formulated to serve the double purpose of cleaning and scavenging the alloy as well as providing a surface protective cover. The crucible and its contents should be raised to a slightly higher temperature than the required pouring temperature. This is to allow for the temperature drop when the crucible is withdrawn, skimmed and deoxidized prior to pouring. Deoxidation of tin bronzes should be carried out as a standard procedure, and 1 to 1½ oz. of phosphor copper per 100 lb. is usually sufficient for this purpose. With ordinary tin bronzes the aim is to deoxidize completely, but to leave only a trace of phosphorus behind. Proprietary deoxidants in accurate amounts are available which are convenient and save time, and are more efficient than bulk phosphor copper, as frequently an appreciable percentage of phosphorus is lost amongst the slag on the metal surface as the piece of phosphor copper floats on the surface. Phosphorus is also volatilized and lost during the long time it takes to dissolve.

Many foundries have found that a positive oxidation/deoxidation process is a guarantee that the alloy will be gas-free when poured. Where a condition favourable to gas absorption exists, or the type of alloy being melted is particularly prone to gas absorption as in the case of nickel alloys, it is desirable to add an oxidizing agent to the metal while melting, or to arrange that the furnace atmosphere is positively oxidizing. The melt is then treated with a deoxidant (in this case a larger amount is required) prior to pouring. This dual process requires to be kept in balance as it is necessary to provide sufficient oxidation to give adequate protection yet at the same time to avoid excessive oxidation, in order that a reasonable amount of deoxidant is capable of dealing with it.

The oxidizing agents in common use are manganese and copper oxides. The deoxidant most favoured for bronzes is phosphor copper; but other deoxidants are used according to the alloy, and may be lithium, boron, silicon, manganese, calcium or magnesium. The amounts necessary to give the best result for any particular alloy under given melting conditions can best be determined by experimental work which should preferably be carried out under laboratory guidance. It is now well known that degassing by means of oxide additions may be more suitable for certain foundry purposes than attempts to control the furnace atmosphere. In a case quoted by Hudson where poor results had been obtained using a brand of oxygen-free copper, the addition of black copper oxide during melting raised the tensile strength from 11 tons per sq. in. to 20 tons per sq. in. The procedure adopted was to make an addition of 1½ per cent of black copper oxide while melting, then to deoxidize the molten copper with 0·01 per cent phosphorus (approximately 1 oz. of phosphor copper per 100 lb.) The zinc was added, then the tin, and a final deoxidation with 0·01 per cent phosphorus was made before casting.

Not much bronze is now made by compounding from virgin ingot. In the rare cases where this is done, it will be found that the addition of the zinc before the tin is good practice, for the reason that zinc is itself a deoxidant, and it is desirable to avoid the formation of tin oxide which would otherwise occur, and which is very difficult to eliminate. The principle of adding an oxidizing agent such as manganese dioxide or copper oxide (or mixtures of both) during the melting of bronze, followed by the necessary deoxidation before pouring, is now a well-established process. Several proprietary degassing materials which provide both protective covers and oxidizing conditions during melting are available, and can be confidently used.

In the past few years, prominence has been given to the process of degassing by the use of nitrogen from cylinders. Well-designed appliances are available for carrying out degassing by bubbling nitrogen through the melt, and many foundries automatically degas all melts as a routine practice. Nitrogen degassing is effective in removing dissolved hydrogen, and the main difficulty is the practical one of finding a long-life, robust degassing tube which will stand up to foundry use and immersion in molten metal at the temperatures involved. As an alternative to the use of nitrogen from cylinders, it is possible to degas by utilizing the decomposition of calcium cyanamide when held at the bottom of the crucible or ladle of molten metal. Disadvantages are the rather slow reaction, the difficulty in finding a satisfactory material for the plunger, and the discomfort to the operator.

FLUXES

The term flux is used to cover a wide range of substances functioning in one or more of the following ways: (1) protective covers to exclude gas and avoid oxidation with consequent metal loss; (2) oxidizing and hydrogen-eliminating agents; (3) cleaning or scavenging agents; (4) deoxidants. The first category includes any substance which forms a gas-excluding cover and prevents oxidation, and which therefore may be a compound which produces a fluid slag, or an infusible material such as charcoal or mixtures of charcoal and other substances. Frequently, materials of this group are combined with materials of the second group, which then give dual-purpose fluxes. Materials of the first group are also often combined with materials of the third group. Fluxes may work: (1) by providing a barrier slag on the metal surface; (2) by direct chemical action with impurities in the alloy and by oxidation; (3) by mechanical action such as the release and bubbling of gas through the metal; (4) by the combination of two or more of these features.

The degassing agents consist usually of metallic oxides and oxygen producing substances, based on the knowledge that the presence of oxygen eliminates hydrogen. In addition to the manganese and copper oxides already mentioned, barium peroxide and nickel oxide are used in certain cases. Air is a cheap oxidizing agent, and the oxidation of a melt can be carried out by bubbling dried air through the molten metal.

GRAIN REFINEMENT OF SAND-CAST BRONZE

Because of the marked improvement in soundness, strength and reduced susceptibility to hot tearing which results when the light alloys are reduced in grain size by treatment with grain-refining agents, it might be expected that the same good effects would follow when copper-base alloys were similarly grain-refined. Work carried out and published by Cibula has indicated that with copper-base alloys this normally is not so. Several effective grain-refining agents were used, including iron or cobalt boride and zirconium carbide or nitride. It was established that although both in well-fed and poorly-fed castings the total porosity was least in alloys of finest grain size, in the fine-grain castings porosity was dispersed right into the outer layers, so that grain-refined castings had poorer pressure tightness and mechanical properties.

On the other hand, where the casting conditions produced columnar structures, shrinkage porosity tended to concentrate at the centre-line of the section, and this gave a sound outer zone which would withstand pressure, provided the columnar zone was not removed in machining. (Note that gunmetal solidifies in two ways: by skin formation and build-up of columnar grains; and by pasty solidification which produces equiaxial grains.) The results obtained by grain-refining were disappointing from a practical foundry point of view, and no attempt seems to have been made by anyone to investigate the effect of grain-refinement on large castings or heavy sections, where the conditions and effect might be different and advantages due to smaller grain size could possibly be expected.

EFFECTS OF REPEATED MELTING

Foundrymen may wonder what the effect of repeated melting is on a gunmetal. To answer this point a series of tests has been carried out, repeating the melting of the same material time after time under ordinary foundry conditions. One hundred lb. of 88/10/2 gunmetal was made up from virgin metals, melting being carried out in a crucible in a coke-fired pit furnace, and using only charcoal as a cover. In all, 31 successive melts of the same material were made; the first 15 had nothing except a charcoal cover, and were not deoxidized prior to pouring. Two test bars were cast from each melt, using a controlled pouring temperature of 1,150 deg. C. throughout the series. After machining and testing, all material with the exception of a small microspecimen was returned to the crucible and the next melt made. After 15 melts, an addition of 0·01 per cent phosphorus was made to each succeeding melt up to the twenty-eighth, when it was evident that a small residual phosphorus content was present, so the final three melts were made without phosphorus addition. The average mechanical properties of the first 15 melts was 17·2 tons per sq. in. tensile, with 20·9 per cent elongation. The average of the second 16 melts was 19·2 tons per sq. in. tensile and 25·5 per cent elongation.

The results of individual melts are shown in Table 3.2 and in graphical form in Fig. 3.10. From this graph it will be noticed that the mechanical properties fluctuated considerably in the first 15 melts which were not deoxidized. Melts 5 and 6 produced bars which were below the specification requirement of 16 tons per sq. in. ultimate tensile strength. In both cases the bars were microscopically unsound, showing interdendritic porosity which is associated with either insufficient feeding, or gas evolution, or both. The test bars were all carefully moulded and run in the same manner and poured at the same casting temperature of 1,150 deg. C., so that variation in feeding should only arise from differences in the feeding characteristics occasioned by the quality of the metal produced by each melt. From experience, and the presence of amounts of oxide films, it was deduced that the porosity was due to interdendritic shrinkage unsoundness caused by the poor feeding properties of the oxidized material.

In the first 15 melts where no deoxidant was used, no subsequent melt equalled the first in tensile strength. In fact, after the first 15 melts it required six melts with phosphor copper additions to restore the tensile strength to the level from which it started, indicating that insufficient deoxidant was used to completely offset the state of oxidation reached by the metal. There seems no reason why at least the initial level of tensile strength should not have been reached with the first phosphor copper addition of the necessary larger amount.

After 31 melts, the batch of metal finished with as high a tensile strength and specific gravity as the original melt, and with greater elongation, and it is considered that these properties could be maintained indefinitely with further melting, although it would be necessary to check and maintain the composition. The test was carried beyond any condition likely to arise in normal foundry usage, and indicates that nothing need

TABLE 3.2
REPEATED MELTING OF GUNMETAL

Melt No.	*U.T.S. tons per sq. in.*	*Elongation on 2 in.*	*Specific gravity*	*Remarks*
1	20·3	24	8·73	A & B
2	17·3	16	8·65	A & B
3	16·5	19	8·47	A & B
4	17·7	22	8·61	A & B
5	13·7	15	8·36	A & B Poor fracture
6	19·2	28	8·56	A & B
7	17·3	17	8·59	A & B
8	15·3	12	8·59	A & B Poor fracture
9	18·9	30	8·62	A & B
10	16·7	17	8·60	A & B
11	17·3	24	8·52	A & B
12	16·5	20	8·42	A & B
13	18·5	24	8·67	A & B
14	17·5	24	8·60	A & B
15	17·1	22	8·53	A & B Average of first 15 melts: 17·2 tons per sq. in., 20·9 per cent elongation
16	18·5	26·5	8·61	A & C
17	17·7	21	8·64	A & C
18	18·5	18	8·68	A & C
19	18·5	22	8·73	A & C
20	18·5	22	8·75	A & C
21	20·1	21·5	8·77	A & C
22	20·7	33	8·75	A & C
23	20·5	27	8·76	A & C
24	18·9	24	8·78	A & C
25	18·1	21	8·75	A & C
26	18·9	25	8·69	A & C
27	19·1	30	8·69	A & C
28	18·9	23	8·70	A & C
29	19·5	30	8·70	A & B
30	21·3	32	8·69	A & B
31	19·7	32	8·74	A & B Average of second 16 melts: 19·2 tons per sq. in., 25·5 per cent elongation

A = Charcoal cover. B = No deoxidant used. C = Deoxidized with P-Cu.

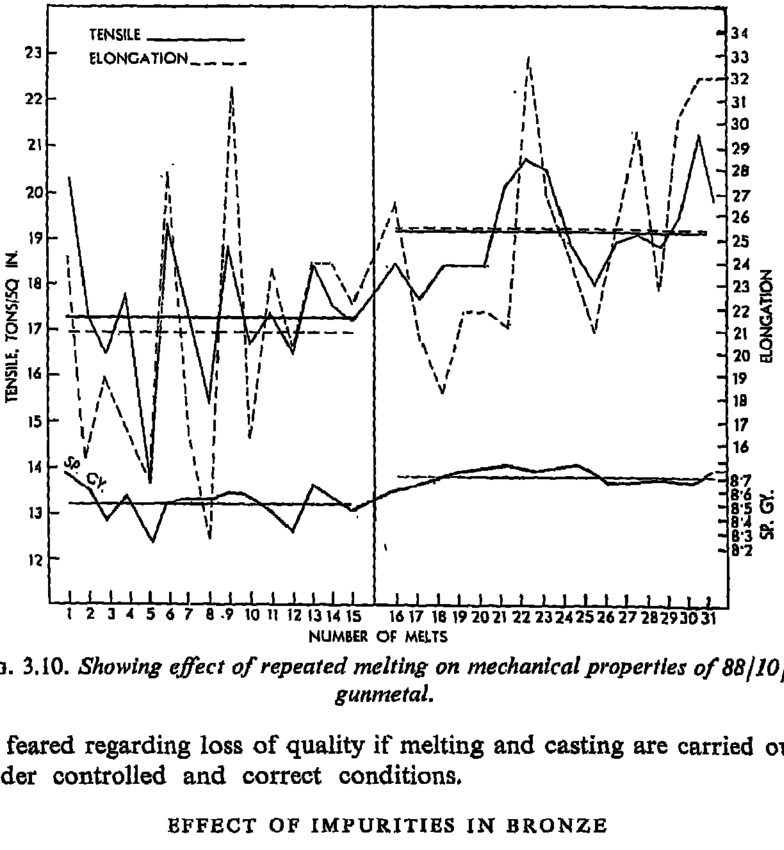


FIG. 3.10. *Showing effect of repeated melting on mechanical properties of 88/10/2 gunmetal.*

be feared regarding loss of quality if melting and casting are carried out under controlled and correct conditions.

EFFECT OF IMPURITIES IN BRONZE

Lead, for a long time, was considered an objectionable impurity in bronze. It is now known that small amounts are beneficial, and up to 1·5 per cent has been found to increase the tensile strength, ductility and resistance to impact. Lead is purposely added to bearing bronze castings to improve the bearing properties, and to castings subject to pressure to increase pressure tightness. It also assists the free-cutting and easy-machining properties due to the fact that lead does not enter into solution, but exists in the structure as isolated globules or lakes. Up to 6 per cent can be added without undue segregation taking place, but above this amount it is necessary to incorporate from 1 to 2 per cent of nickel, according to the lead content.

Iron is present in all non-ferrous alloys, and it is normally impossible for the foundry to eliminate it. In the amounts usually found it is not detrimental; that is to say, under 0·3 per cent has little if any effect on the mechanical properties. The greatest danger of iron pick-up arises during the remelting of turnings and borings. Efficient magneting machines are available, and all swarf should have the free iron removed by magneting before melting. The prolonged immersion of unprotected iron skimmers or stirrers will result in an increase in the iron content due to the solvent action of bronze at high temperatures. High iron content (i.e. over 0·5 per cent) will cause trouble in casting, as such metal may be lacking in fluidity and tend to give dirty castings. As iron is only soluble to the extent of approximately 0·2 per cent, amounts above this figure result in quantities of iron-rich particles in the structure which increase the hardness or result in hard spots and may even cause unprotected machined surfaces to rust.

Zinc can be regarded as a hardening constituent, being approximately equal to half its amount of tin when present in bronze. Zinc acts as a deoxidant, and when making bronze from virgin metals it should be added after initial deoxidation with phosphor copper and before the tin is added. The presence of zinc improves the fluidity and castability of a bronze, and the alloy 85 copper, 5 tin, 5 lead, 5 zinc is one of the most widely used. The vapour pressure due to the presence of high amounts of zinc tends to retard gas absorption, and this is particularly so in the case of brass.

Zinc is one of the main constituents of brass, and it is important to maintain it at the specified compositional level in order to obtain the correct mechanical properties, particularly in high-tensile brass. Below approximately 39 per cent zinc the structure of brass consists of the α constituent which is comparatively ductile. Above this amount, the β constituent is formed, having high tensile strength but low elongation. The high-zinc-content alloys should be rapidly melted and removed from the furnace as soon as the correct casting temperature has been reached, otherwise there will be high melting losses due to loss of zinc, accompanied by a compositional and structural change.

Foundries casting high-tensile brass usually find it necessary to assess the zinc content by a pre-casting test, which may consist of breaking small chill-cast bars and examining the fracture. This may be followed by a rapid determination of the copper content or microstructure examination.

Phosphorus is usually added in the form of 15 per cent phosphor copper, the main use of which is as a deoxidant. When used for this purpose, only sufficient should be added to deoxidize and leave little more than a trace when it has completed its work. It is also used for alloying purposes to make phosphor bronze. A very small amount goes into solution, and above this the well-defined copper phosphide (Cu_3P) is formed which, when present, is associated with the $\alpha + \delta$ eutectoid as shown in Fig. 3.6. Copper phosphide in itself is comparatively hard and brittle, and increases the Brinell hardness and lowers the solubility of tin in copper. Alloys containing phosphorus in quantity show larger amounts of the $\alpha + \delta$ eutectoid in the structure.

Nickel. Owing to the increase in the amount of nickel alloys used in modern engineering, most secondary bronze contains some nickel. It is not detrimental in any quantity which is likely to be picked up by chance contamination from nickel-bearing scrap, but rather the reverse, as tensile strength and elongation are slightly improved. It will be noted that amounts of 1 to 2 per cent are desirable in leaded bronze. The presence of nickel in this class of material is to aid in the prevention of lead segregation by speeding up initial solidification, and providing a copper-nickel network which holds the lead in small globules and prevents agglomeration into large masses. Purposely added in larger amounts, nickel gives a series of high-strength alloys and has very useful physical properties for special services. A complete new range of alloys with remarkable high-temperature properties—the Nimonic series—has made possible the development of the jet engine.

Aluminium is a constant hazard in the non-ferrous foundry producing gunmetal castings, as aluminium alloys are used to such an extent that there is always the possibility that bought-in scrap may contain an odd portion of aluminium bronze, which may pass unnoticed. Borings or turnings coming back from the machine shop may also be contaminated with an amount of aluminium alloy. A very small amount of aluminium finding its way into bronze—even as little as 0·01 per cent—will cause trouble, and higher amounts will result in loss of strength due to oxide films and inclusions, which will show up in machining and result in porosity and lack of pressure tightness. Fortunately, the cause is usually apparent, as aluminium-contaminated bronze shows whitish areas on the cast skin, and also in the fracture. Bronze contaminated by aluminium can be successfully treated with aluminium-removing fluxes which are commercially available for the purpose.

Sulphur. Until recently, the effect of sulphur has been a debatable point among non-ferrous foundrymen, and it has been held to be responsible for a number of troubles and difficulties ranging from low strength and poor fluidity to porosity. Gunmetals readily absorb and react with sulphur dioxide which is always present in the furnace atmosphere from the combustion of the fuel, particularly oil fuel. Commercial castings, therefore, can contain amounts of sulphur up to 0·25 per cent according to the degree of exposure. Work carried out by the British Non-ferrous Metals Research Association has shown that with up to 0·3 per cent sulphur there is no effect on fluidity, castability, or porosity.

Silicon is not a harmful impurity so long as the lead content is low;

but in leaded bronze, it has a very bad effect, as it reacts with lead oxide to form lead silicate, and this affects both the mechanical properties and pressure tightness.

Arsenic. Not much is known of the effect of arsenic, but in amounts up to 0·20 or even 0·30 per cent it appears to have no noticeable effect.

Bismuth is a dangerous impurity, but it would not normally be present in any more than a trace in commercially produced bronze. In the event of poor physical properties, unsound castings, or lack of pressure tightness, where the melting and casting conditions are satisfactorily established and above suspicion and all other possible irregularities have been investigated, chemical impurities may be suspected. The likeliest contaminant is aluminium, but this is readily detected. Micro-examination in the first place, confirmed by chemical analysis later, will be necessary to indicate the presence of other harmful impurities. While it is impossible to exclude the possibility of impurities as a cause of foundry trouble, they should be considered only when all other methods of eliminating trouble have proved negative.

CASTING TEMPERATURE OF BRONZE

Assuming that satisfactory melting conditions are established, it is of equal or even greater importance that correct and controlled casting temperatures are used. One of the most important advances which any non-ferrous foundry can make is to become equipped with at least one reliable pyrometer and establish temperature control for melting and pouring. Having done this, it is essential that the temperature control be applied consistently. In the average non-ferrous foundry, no other single action can produce such immediate dividends in the way of decreased scrap. In the larger foundries, temperature control can preferably be made the responsibility of one technician, and it may be possible to combine this duty with the responsibility for deciding on the placing and sizes of runners and risers as well as fixing the pouring temperature for individual castings. Complete records should be kept, either separate in book form, or on the pattern cards; and in time a store of recorded experience would be available for guidance. A casting repeated some time in the future could then, if previously made satisfactorily, be run and fed in the same way and cast at the same temperature. In this connexion it should be remembered that an alteration in the method of running may necessitate a change in the casting temperature.

In determining the actual pouring temperature for any individual casting, the section, mass and distance the metal has to be run through the mould must all be considered. In the case of 88/10/2 bronze, the normal range is from 1,100 to 1,240 deg. C., heavy castings being poured at

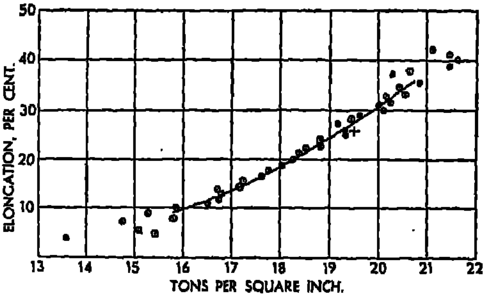


FIG. 3.11. *Relation between tensile strength and elongation in 88/10/2 gunmetal (Laing and Rolfe).*

the lower end and thin-sectioned castings at the higher end of the range. In the case of 86/7/5/2 and 85/5/5/5 brasses, the casting range is slightly lower, from 1,080 to 1,200 deg. C., again depending upon the size and mass to be cast.

The presence of phosphorus has a marked effect on apparent fluidity and enables lower pouring temperatures to be used. The combination of high lead and phosphorus has an even more marked effect, and with high-lead alloys the casting temperature for test bars is as low as 1,000 deg. C.

TENSILE STRENGTH AND ELONGATION

Examination of the results of a number of tests will show that there is a connexion between the tensile strength and the elongation of a tin bronze; this relationship is shown in Fig. 3.11, which reproduces a graph prepared by Laing and Rolfe from the classified averages of 679 tests. The average of all tests gave figures of 18·4 tons per sq. in. tensile with 29·5 per cent elongation, and average figures obtained by the present author over 10 years gave figures of 19·5 tons per sq. in. tensile with 25·5 per cent elongation. These figures fall into line with the graph in Fig. 3.11 and represent a point on it marked X. There is a certain amount of scatter below 16 tons per sq. in. and above 20 tons per sq. in., which is understandable, but otherwise the figures give a remarkably uniform curve. It may be misleading to compare sets of test-bar results from different foundries, unless these results have been obtained on the same shape and size of test bar and cast in the same manner.

DENSITY AND TENSILE STRENGTH

In the same way that there is a relationship between tensile strength and elongation, there is also a relation between the density and tensile strength. The density of a casting or a test bar may be used as a criterion of the quality or soundness, providing the material has been cast at the correct temperature. Density is a good indication of soundness in the case of test bars poured at the same temperature, or a number of similar castings poured at the same temperature. There is a general relationship

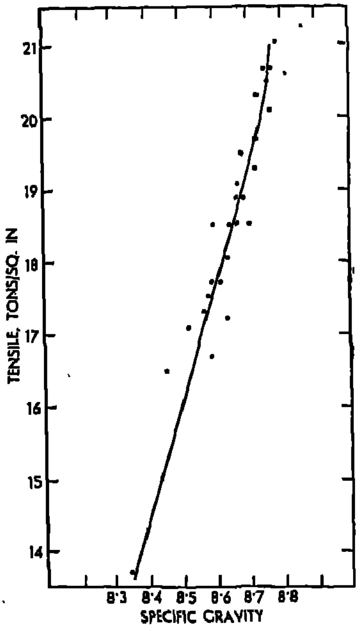


FIG. 3.12. *General relationship between the density and tensile strength of 88/10/2 gunmetal (all bars cast at 1,150 deg. C.).*

between density and tensile strength, as shown by Fig. 3.12, although this is not so close as that of tensile and elongation. The figures in the graph were compiled from a number of test bars all cast at 1,150 deg. C.

ALUMINIUM BRONZE

The mechanical properties of the aluminium bronzes are outstanding. They have high strength, capable of further improvement by heat treatment; considerable resistance to corrosion, oxidation and wear; and are of a rich attractive golden colour. Aluminium bronzes are primarily alloys of copper with usually not more than 10 per cent aluminium, and containing also iron, manganese and nickel, either singly or in combination.

The copper-aluminium equilibrium diagram of Fig. 3.13 (reproduced from *Equilibrium Diagrams of Binary Copper Alloys*, issued by the Copper Development Association) indicates that aluminium is, theoretically, soluble in copper to the extent of approximately 9·4 per cent. In practice, as the alloy is not a simply binary alloy, the α solubility limit is rather lower, being under 8 per cent aluminium. Above this amount, duplex structures result. One very important feature will be noted, namely the very narrow freezing range which necessitates generous feeding arrangements. Alloys containing between 8·5 and 11 per cent aluminium cover the range of commercial castings, and give a very good combination of high yield and high tensile strength with good ductility and toughness.

The straight copper-aluminium alloys, when cast in heavy section, are prone to a trouble which was known as "self-annealing" in the early history of the alloy. The effect is to produce a coarse structure with poor mechanical properties. Referring to the equilibrium diagram, it will be seen that slow cooling below 570 deg. C. results in the β breaking down to a fully resolved $\alpha + \gamma_2$ structure. This structure accompanies the state of self-annealing, and indicates that the rate of cooling has been

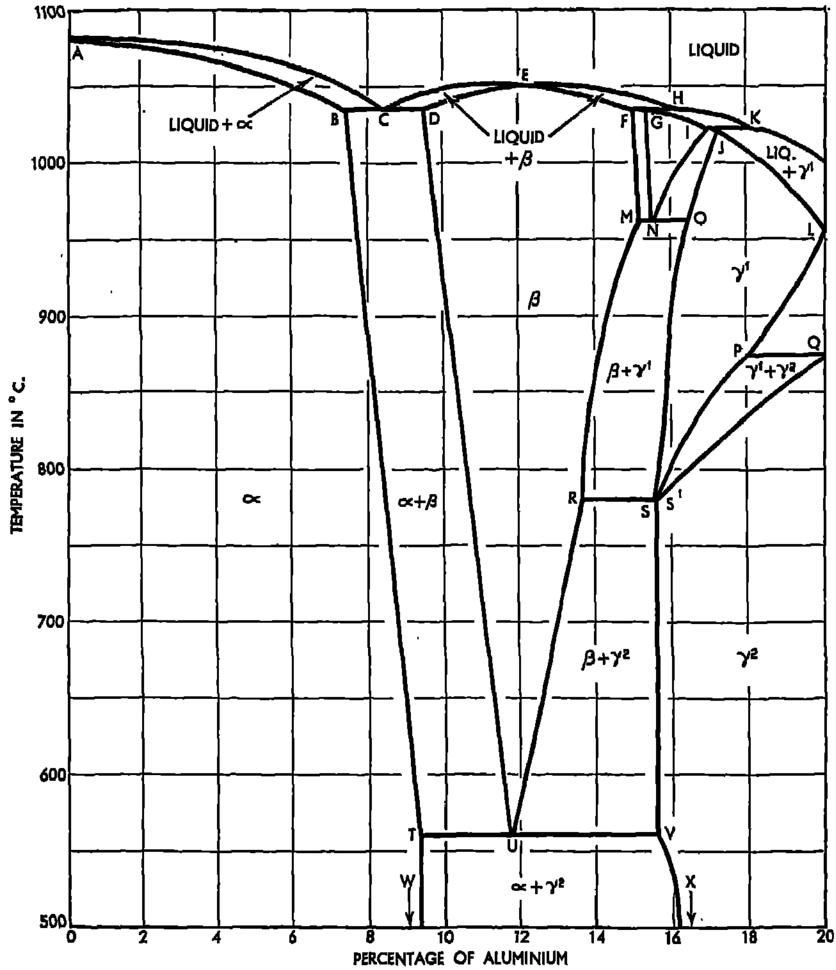


FIG. 3.13. *Copper-rich portion of the system aluminium-copper, from "Equilibrium Diagrams of Binary Copper Alloys" (Copper Development Association). From the Institute of Metals annotated equilibrium diagrams Series No. 4, prepared by Prof. G. V. Raynor.*

sufficiently slow to allow more or less equilibrium conditions to be reached. If the alloy is quenched or the cooling is otherwise sufficiently rapid, complete breakdown of the β is prevented. Examination of the dark constituent of a duplex structure at high magnifications shows that this is a constituent which varies with the rate of cooling. Self-annealing does not occur in chill castings, and usually not in sand castings until a section of 1 in. has been exceeded. This can probably be avoided by chilling, or by additions of either 3 per cent nickel or iron. If self-annealing has taken place, as it may in a straight alloy, the properties may be restored by heat treatment.

EFFECT OF ADDED METALS IN ALUMINIUM BRONZE

Iron is a cheap and very valuable addition to aluminium-bronze. It gives grain refinement which results in improved mechanical properties and, as already indicated, aids the prevention of self-annealing.

Nickel also has a grain-refining action and increases the tensile strength, but elongation then falls off considerably. Iron and nickel can be used together, the combination giving very superior properties in the as-cast state. One well-known composition is B.S. 1400 A.B.2–C which is a 10 per cent aluminium alloy with approximately 5 per cent iron and 5 per cent nickel, and having a tensile strength of 42 to 45 tons per sq. in. and an elongation of over 15 per cent. Nickel is said to increase still further the resistance to corrosion.

Manganese is somewhat similar to iron in that it confers grain refinement and enhanced mechanical properties.

Deoxidation. Apart from any which may be incorporated in the alloy, manganese is also added as a deoxidant, although it cannot be considered to be particularly active in this respect. A residual amount of 0·3 per cent is commonly aimed at; but for deoxidation purposes, it is preferable to add magnesium to the extent of at least 0·02 per cent along with the manganese. Although the reason seems a little obscure, it has been found that treatment with a further addition of pure aluminium is also effective where the alloy is known to contain oxide films.

In general there is an analogy between aluminium bronze and steel, as the aluminium bronze when quenched from a high temperature, gives greater strength with lower ductility, and these properties can be further improved by a subsequent tempering treatment. Furthermore, as with steel, the heat treatment necessary varies with the size and section of the castings, and small castings generally give better results.

FOUNDRY CHARACTERISTICS OF ALUMINIUM BRONZE

One of the outstanding features, and one which constitutes a difficulty, is that because of the aluminium content, aluminium oxide is very readily formed on all freshly exposed surfaces, particularly at the high melting and pouring temperatures which are necessary. Once formed, aluminium oxide cannot be reduced again; ordinary deoxidants have no effect. If the aluminium oxide is stirred or churned into the metal it tends to remain in suspension and does not separate very easily. Where this occurs, it may be found later throughout the alloy as patches of whitish inclusions after machining. To minimize and avoid this type of defect, copper of high purity should be carefully melted and deoxidized before adding the aluminium. The copper is melted under a suitable cover flux and deoxidized with 0·3 per cent manganese. Aluminium can be added as pure aluminium, but it is preferable to use a 50/50 copper-aluminium alloy previously prepared. If iron is to be added it should be compounded in the 50/50 master alloy. Nickel is added either as shot or, preferably, as a master alloy. The most carefully made and melted oxide-free material will still produce defective castings if churned up with air by either careless stirring or pouring. Agitation and turbulence must, therefore, be avoided, and the metal introduced into the mould in such a manner that a smooth, unbroken, steady flow results.

The safe rule in casting aluminium bronze, as with other non-ferrous alloys, is to cast at the lowest temperature that will safely run the job. The actual casting temperature range is similar to that for 88/10/2 gunmetal, and is approximately 1,120 to 1,250 deg. C.

The gating, running and feeding techniques resemble that necessary for high-tensile brass, and the same precautions must be observed. On account of the oxide-forming propensities, the metal should be arranged to enter and fill the mould quietly and smoothly, and the mould must be such that when it is filled, the metal will solidify against the mould face without any bubbling or disturbance. It is preferable to bottom-pour, using liberal dross sumps as in high-tensile brass practice, and to gate on to a heavy section. Large feeding heads are required, and here again the practice resembles that of high-tensile brass. Aluminium bronze is rather susceptible to gas pick-up, and for that reason it is preferable to use foamed-plaster insulating sleeves (described later) to reduce the amount of metal required in the feeding heads rather than risk the use of exothermic sleeves which may feed the casting with gassy metal. Because of the large heads required, the casting yield would be considered good at 60 per cent, but the average yield without assisted feeding would normally not reach this level. With the use of heads in foamed-plaster insulating sleeves the amount of feed metal can be considerably reduced, and the yield can be brought up to at least 75 per cent, which results in substantial economy.

SILICON BRONZE

Silicon bronze came into prominence during the Second World War due to the shortage of tin, but it does not seem to be used to any great extent at the present time. Two well-known silicon-bronze compositions are "P.M.G." metal and "Everdur", and these have been more or less embodied in one specification, namely, B.S. 1400: 1948, SB1–C.

Silicon bronze is undoubtedly superior to 88/10/2 gunmetal as regards tensile strength (20 times per sq. in. tensile strength and 15 per cent elongation is specified). The elongation necessary is somewhat harder to achieve, and its characteristics as a casting alloy make it rather unpopular in the foundry, and definitely a danger where high-lead alloys are also being cast. Casting characteristics may be assessed as between those of 88/10/2 gunmetal and high-tensile brass. The reason that silicon bronze is not popular seems to be due to the fact that whilst it is regarded as an alternative for gunmetals, its characteristics necessitate treatment in the class of high-tensile brass. As long as tin remains at a price which enables gunmetal to be used, silicon bronze will be at a disadvantage in competing with gunmetal at the price of the latter.

Silicon bronze is prone to excessive gas absorption during melting and a suitable flux cover is necessary. The average casting temperature is about 1,130 deg. C. and the casting range is similar to that of 88/10/2 gunmetal. It has a short freezing range of only 50 deg. C., and the rapid solidification and greater shrinkage necessitate larger feeding heads and runners than gunmetal; but where the feeding is adequately catered for, satisfactory high-strength castings can be obtained. Where leaded tin-bronzes are being cast in the same foundry, the greatest care must be taken to avoid any mixing of the alloys, as either one in the other will be a cause of trouble.

Silicon is soluble in copper to an amount approaching 4 per cent forming the α-solid solution; above this amount the κ constituent appears. Iron is practically insoluble in the α-solid solution, and therefore appears in the structure as small crystallites. Manganese, in the amounts usually added, is completely soluble and consequently does not appear as a separate constituent under the microscope.

NICKEL ALLOYS

Nickel is being increasingly used as an addition to non-ferrous casting alloys. Generally, nickel increases strength, particularly the yield point, and assists in the maintenance of good mechanical properties at elevated temperatures; it lessens the grain size, increases resistance to corrosion, and in some alloys enables superior physical properties to be obtained with heat treatment. The alloys containing nickel may be very broadly classified as containing under 5 per cent nickel; between 5 and 10 per cent nickel; between 10 and 20 per cent nickel; special alloys with nickel as the base, such as high-nickel bronzes, Monel, Inconel, and alloys in the Nimonic group. (Monel, Inconel and Nimonic are trade marks of Henry Wiggin & Co. Ltd.)

The use of up to 2 per cent nickel to lessen lead segregation in the leaded phosphor bronzes has been mentioned, but it is desirable to point out that castings which are to be used as direct bearings should not, with certain exceptions, contain more than 2 per cent nickel, as amounts above this are believed to harm the bearing properties. The exceptions are special bearing alloys containing some 40 per cent nickel, 8 to 10 per cent tin, 8 to 10 per cent lead, and the balance copper, widely used for centrifugal-pump shroud and sealing rings and where corrosion resistance as well as bearing properties is essential. Alloys for service at elevated temperatures or which are to be heat-treated should preferably not contain lead in any appreciable quantity, nor should lead be present in any alloy in which silicon occurs, owing to the formation of a lead-silicate slag.

Alloys in the first group, with small additions of nickel, hardly require special mention, as they are no more difficult to handle in the foundry and require no modification to the existing good practice. An alloy of 88 per cent copper, 5 per cent tin, 5 per cent nickel, and 2 per cent zinc has been used advantageously and possesses outstanding mechanical properties, especially when heat-treated; it being possible with full heat treatment to obtain 35 tons per sq. in. tensile strength with 15 per cent elongation. With modified heat treatment, 30 tons per sq. in. tensile strength and 10 per cent elongation can be obtained. Even as cast, properties superior to Admiralty gunmetal may be obtained, particularly as regards yield point and resistance to impact.

When over 5 per cent nickel is present the bronze begins to take on nickel-bronze characteristics. As the nickel content is increased the alloys require correspondingly higher melting and pouring temperatures, and become increasingly susceptible to gas absorption. With over 10 per cent nickel, a further difficulty arises, as carbon can be absorbed which will then react with any oxides present, resulting in the formation of carbon monoxide. This can behave in a similar manner to hydrogen, going into solution during melting and being thrown out again on solidification, resulting in gas porosity in the final casting. Prolonged melting increases the absorption of both sulphur and carbon, resulting in brittleness of the final alloy. Both sulphur and carbon should be kept to a minimum, so that charcoal is not permissible as a surface cover.

Nickel bronzes require rapid melting, and positive oxidizing conditions are essential, particularly during the super-heating period. These are ensured by covering the surface of the molten metal with 0·5 to 1 per cent dry manganese dioxide, black copper oxide or nickel oxide. Melting must be followed by very thorough deoxidation. In the higher nickel-content bronzes, metallic manganese, silicon and magnesium are used as deoxidants. The presence of sulphur in the form of nickel sulphide is particularly deleterious, because the nickel sulphide exists as inter-

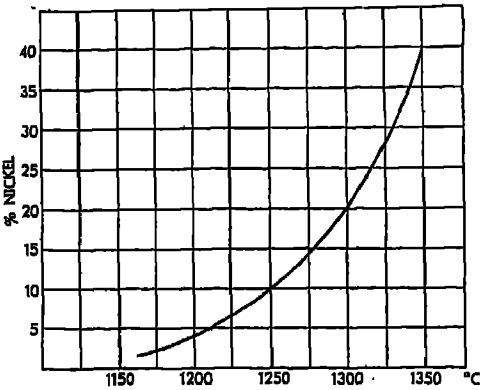


FIG. 3.14. *Variation of pouring temperature with nickel content for medium castings.*

granular films which have a melting point of approximately 630 deg. C. and are very brittle at ordinary temperatures. The use of magnesium is necessary, therefore, not only as a deoxidant, but because of its preferential combining power with sulphur. At least 0·1 per cent should be present after deoxidation in all nickel alloys; and this will fix up to 0·08 per cent sulphur as magnesium sulphide, distributed as small and relatively harmless particles uniformly throughout the structure.

As the nickel content is increased, the freezing point and the melting and pouring temperatures are naturally raised considerably. Fig. 3.14 gives an indication of the average pouring temperatures required for medium castings throughout the range of nickel bronzes. When appreciable amounts of nickel are present (above 5 per cent) a thicker oxide film is formed on the pouring stream and it becomes necessary to use choke gates. There is also greater shrinkage and hot shortness as compared with ordinary tin bronze. This necessitates increased feeding with the provision of adequate

FIG. 3.15. *Structure of high nickel bronze.* × *50 (Hudson).*

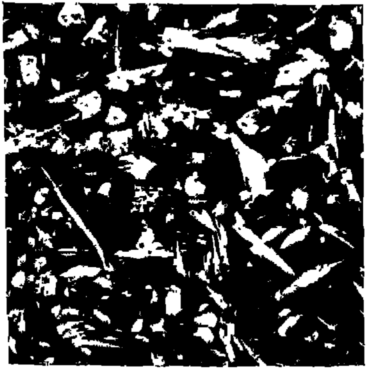


FIG. 3.16. α-β *structure of high-tensile brass.* × *50.*

risers, and the use of moulds which will "give" sufficiently to avoid hot cracking. The structure of a high-nickel bronze is shown in Fig. 3.15.

Precipitation Hardening. Precipitation hardening depends upon the alloy taking into solution at a high temperature a constituent which is less soluble (or insoluble) at a lower temperature; and which is therefore precipitated, or partially precipitated, either on cooling or by submitting the material to a further tempering treatment.

Copper and nickel form a continuous series of solid solutions; therefore alloys of copper and nickel alone are not susceptible to precipitation hardening. The three elements which produce precipitation hardening are tin, silicon and aluminium. In the case of silicon additions, the precipitation hardening constituent is Ni_2Si; and when aluminium is present, the precipitation hardening constituent is usually regarded as being a solid solution of Cu_3Al and NiAl.

HIGH-TENSILE BRASS

The commonly used name, manganese bronze, is that given to a range of high-tensile brasses. The alloy is not really a bronze but a brass, and the principal characteristics are not primarily due to the effect of manganese alone, which may only be present in small amounts. The basic composition is a brass of the Muntz-metal type, which may range between 53 and 60 per cent copper. The alloying metals usually added are tin, iron, nickel, manganese and aluminium. The physical properties required, and the conditions to be met in service, necessitate a fairly wide compositional range. The composition may be adjusted to give two types of structure with different mechanical properties: (1) a duplex α-β structure, and (2) an all-β structure. A duplex α-β structure will give about 35 tons per sq. in. tensile strength with 30 per cent elongation (as illustrated in Fig. 3.16) whereas the all-β structure materials have higher tensile strengths of 48 tons per sq. in. or over, but with a lower elongation of 20 per cent.

The various added metals which comprise the composition have the property of entering into solid solution and replacing zinc in the structure, with the exception of nickel which behaves in the same way as copper in the structure. The zinc replacing equivalent, or "fictitious zinc values," for the various metal additions were investigated by Guillet in a classical research, and the values then determined are reliable enough to provide a guide to the structure which can be expected from any particular composition. The coefficients of equivalence as determined by Guillet are:

Tin is equivalent to × 2 zinc
Lead is equivalent to × 1 zinc
Iron is equivalent to × 0·9 zinc

Aluminium is equivalent to × 6 zinc
Manganese is equivalent to × 0·5 zinc
Silicon is equivalent to × 10 zinc

Nickel behaves in the same way as copper in the structure.

The total zinc value, or fictitious or effective zinc, can be calculated from the formula:

$$\text{Total zinc value} = \frac{(\%\ \text{zinc} + \%\ \text{added metal} \times \text{coefficient}) \times 100}{\%\ \text{copper} + \%\ \text{zinc} + (\%\ \text{added metal} \times \text{coefficient})}$$

Three high-tensile brasses are specified in B.S. 1400: 1948. They are HTB1, which is an α-β material; HTB2, which has a minimum of 15 per cent α; and HTB3, which is an all-β material. A straight copper-zinc brass has an α structure when the zinc content does not exceed approximately 39 per cent, but the percentage varies according to conditions. (If cooled slowly enough, it can show some β even down to 33 per cent zinc.) At 39 per cent zinc, the β constituent begins to appear and duplex structures result up to 46·6 per cent zinc, when the structure becomes all-β. At 50·6 per cent zinc the γ constituent appears, but such alloys are not used commercially owing to the embrittling effect of the γ constituent. As approximately 39 per cent zinc is the point at which β begins to appear, and 46·6 per cent is the point at which the structure is fully all-β, then the addition of 7·6 per cent zinc is responsible for the change from all-α to all-β. It would be expected that a structure of 15 per cent α would result from a total zinc content of 45 per cent zinc approximately.

As an example, HTB2 is specified to show a proportion of the α phase not less than 15 per cent of the total area. The specification permits maximum additions of 3·0 per cent manganese, 5·0 per cent aluminium,

TABLE 3.3

HIGH-TENSILE BRASSES

Composition	EXAMPLE 1		EXAMPLE 2	
	Per cent	*Zinc value*	*Per cent*	*Zinc value*
Copper	58·0	—	55·0	—
Tin	1·0	Has a total zinc equivalent value of 43%, giving an α-β structure	1·0	Has a total zinc equivalent value of 47·5%, giving an all-β structure.
Lead	0·2		0·2	
Iron	1·0		1·0	
Manganese	0·25		2·0	
Aluminium	0·2		1·0	
Zinc	39·35		39·8	

up to 2·5 per cent iron, 2·0 per cent nickel, 0·5 per cent tin, 0·5 per cent lead, 0·1 per cent silicon, and 0·2 per cent other elements. The minimum copper content is specified as 55·0 per cent and with the maximum permitted additions the zinc content would be approximately 31·2 per cent, but the fictitious zinc value would be almost 54 per cent, and this could result in a structure with a β matrix containing the γ constituent. It is left to the discretion of the user, therefore, to arrange the composition within the specification to give the correct structure with the best mechanical and general properties, and this can be done in several ways. One composition which fulfils the requirements of approximately 45 per cent zinc value could be the following:

Per cent				
58·5	Copper			
2·0	Manganese	×	0·5	= 1·0
2·0	Aluminium	×	6	=12·0
1·0	Iron	×	0·9	= 0·9
1·5	Nickel			
0·5	Tin	×	2	= 1·0
0·3	Lead	×	1	= 0·3
				15·2
0·2	Other elements			
34·0	Zinc by difference			

This composition would have a total zinc value of:

$$\frac{(34{\cdot}0 + 15{\cdot}2) \times 100}{60{\cdot}0 + 34{\cdot}0 + 15{\cdot}2} = \frac{4{,}290}{109{\cdot}2} = 45{\cdot}0 \text{ per cent zinc value.}$$

Examples of an α-β material and another material having an all-β structure are given in Table 3.3.

ADDITIONS AND IMPURITIES IN HIGH-TENSILE BRASS

Tin is added for the improved resistance to corrosion which it imparts. It enters into the solid solution in both the α and β constituents up to a total amount of approximately 1·3 per cent. Normally the amount added should not exceed 1 per cent, and some compositions do not include tin.

Lead is not purposely added, and the small amount usually found may be an indication of the quality of zinc used, or may come from the scrap, where this is incorporated.

Iron plays an important part, but is not soluble to any great extent, and forms a complex iron-rich constituent with copper and probably some tin, manganese or aluminium. This constituent, known as the "iron-rich

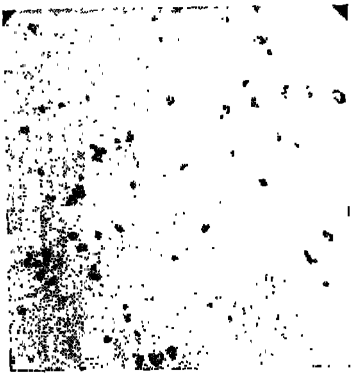


FIG. 3.17. *The iron-rich "blue etching constituent" in high-tensile brass.* × *100.*

complex" or the "blue-etching constituent," provides nuclei for crystallization, imparting a fine grain size. This constituent is shown in Fig. 3.17.

Manganese. The principal effect of moderate amounts of manganese is that of a deoxidant, and it improves the tensile strength.

Nickel is not a zinc-replacing element, but behaves as copper. It is not essential to incorporate nickel in a manganese brass, but its presence is believed to increase corrosion and erosion resistance, and it is therefore often added to manganese brass for use in marine propellers.

Aluminium has a high coefficient of equivalence, so that small amounts have an important effect on both the structure and the mechanical properties.

Phosphorus, silicon and magnesium require to be kept out of manganese brass, and silicon and magnesium in particular are deleterious as both reduce ductility.

FOUNDRY CONSIDERATIONS

Due to the vapour pressure of zinc at melting temperature, manganese brass, in common with other brass compositions, is relatively immune to hydrogen absorption during melting, although it is known that the use of a flux containing an appreciable proportion of cryolite (which will remove the protective oxide film) can result in gas absorption. Although gas absorption does not normally present a difficulty, there are many other hazards associated with the sound casting of the alloy and it necessitates skill and experience to obtain consistently successful results. The freezing range is short and the solidification shrinkage is high, so that provision has to be made to ensure adequate feeding by means of large feeder heads and risers or by special feeding aids as will be mentioned later; together with the use of chills to speed the solidification of heavier masses where necessary.

Because of the aluminium incorporated, a tough skin of aluminium oxide is formed on all liquid-flowing surfaces; and to avoid excessive dross formation, oxide inclusions and entrapped bubbles, the metal must enter the mould quietly and without turbulence. This is usually best achieved with bottom pouring, and choke gates, dross sumps and traps are essential. The feeding heads require to be large, and the casting yield may be only 50 per cent or less.

For castings up to ½ cwt., a choke gate should be employed, as shown in Fig. 3.18 (*a*), and the runner should lead into a generously dimensioned open-feeding riser situated close to the casting (*d*). Castings above ½ cwt. should have an ample pouring basin, closed with a well-fitting plug which is gently withdrawn when the basin is full (*b*). When the casting is filled and the metal is entering the feeding heads, the pouring is stopped and the runner closed off; hot metal is then gently added to the feeding heads.

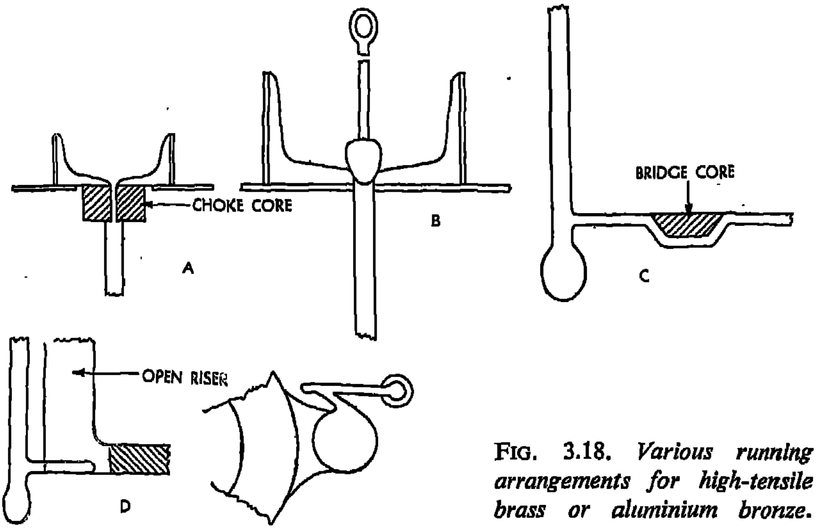


FIG. 3.18. *Various running arrangements for high-tensile brass or aluminium bronze.*

All down gates should have a dross sump at the base, and wherever a change in direction occurs—as for the ingate—it will be desirable to provide a dross trap by means of a bridge core as at (*c*), and this may be combined with either the (*a*) or (*b*) type pouring basins. Flat castings may be run by the large open-feeding riser method as shown at (*d*). Deep cylindrical castings can be run from an annular ring below the casting with evenly dispersed vertical gates connecting with the mould space and increasing in section as they approach it.

In spite of the low casting temperature which is employed, manganese brass has good fluidity and this is useful because of the low pouring speeds and slow filling of moulds which are necessary. The pouring temperature naturally varies with the size and weight of casting, the range being approximately 960 to 1,040 deg. C., with 1,000 deg. C. as an average temperature for pouring medium castings. To ensure adequate feeding of test bars,

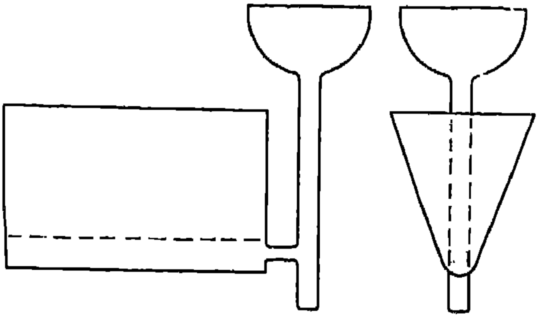


FIG. 3.19. *Method of running high-tensile brass test bar. Bar is cut from bottom of wedge, as shown by dotted line.*

these may be attached longitudinally to a heavy section; or when cast separately, the keel-type test bar should be used as illustrated in Fig. 3.19.

ASSISTED FEEDING

There is a marked difference in the manner in which long-freezing-range alloys and short-freezing-range alloys feed; 85/5/5/5 bronze may be taken as an example of the former type, and high tensile brass of the latter. Long-freezing-range alloys solidify in a pasty manner, and according to work carried out by the British Non-ferrous Metals Research Association, shrinkage is compensated in two ways. One is by general consolidation of the pasty copper-rich crystals and liquid which settles or packs due to hydrostatic and atmospheric pressure, which is termed mass feeding. This occurs whether the casting has extraneous feeders or not, and mass feeding can compensate for at least 60 per cent of the total shrinkage. The second phase is due to an influx of residual liquid into the pasty mass via the channels between the dendrites and crystals, after the first effect has occurred. This presupposes a temperature gradient between the mass being fed and the reservoir or feeding head from which the liquid is drawn.

With this type of alloy, and using low casting temperatures, small castings might be produced without feeders and show no more than 2½ to 3 per cent porosity, but would probably have slight surface sinks which the use of feeders would eliminate.

With larger castings at normal pouring temperatures, it is necessary to use feeders, and these should be of good height to give hydrostatic pressure and also remain liquid so as to utilize atmospheric pressure. High tensile or manganese brass is an example of a skin-forming alloy which solidifies within a narrow range of temperature, a solid layer forming at the mould face and solidification then moving progressively inwards. In this case, the feeder and connecting channel should remain liquid as long (and preferably longer than) the casting, and liquid metal will then flow in as required to compensate for the concentrated shrinkage which occurs at the section centre.

The large feeders which it is necessary to provide, particularly for aluminium bronze and manganese brass, have been mentioned earlier. These are necessary to provide metal to make good the loss of volume which occurs during the solidification of the casting due: (1) to the drop in temperature between the pouring temperature and the temperature when the alloy is just solid; (2) to the change of volume while the alloy is changing from the liquid to the solid state.

The combined effects amount to approximately 4½ to 5 per cent for the alloys mentioned, but in order to supply this 5 per cent feed metal to the casting, a considerably larger amount of metal is required in the feeding head, so that the large mass will retain sufficient heat to remain liquid until the casting has solidified and so enable the required 5 per cent to be supplied in a fully fluid state over as long a period as the casting requires feeding. This may necessitate a feeding head which is of the same weight as the casting itself and which, with the runner system, may mean that the ultimate yield of castings is only about 30 to 40 per cent. Three times the weight of the casting will have to be melted, in consequence, and as non-ferrous alloys are costly and the metal loss operates on the total amount melted, any way of reducing this amount will assist in lowering the cost of the casting.

Direct economy will result when the feeding heads are made smaller; and further economy will follow, as smaller heads mean less cutting off and fettling.

Methods which permit the size of the feeding heads to be reduced include any means whereby a smaller mass of metal can be kept molten over a longer period—in fact, until the casting has set. There are two practical ways of achieving this: (1) supplying additional heat by means of an exothermic material, and (2) surrounding the feeder with an insulating material in order to prolong the fluidity by retarding the cooling rate.

An insulating material is cheaper than an exothermic material, so that an insulated feeder should be considered first, and if the conditions are not suitable, then an exothermic material may be chosen. The insulating sleeve material used is made from a special high-strength gypsum plaster. To ensure permeability and maximum insulating value, it is prepared by foaming, whereby the plaster, when set, has a cellular structure of about 50 per cent voids which are interconnected to ensure the desired permeability. This is required in the event of the presence of a small amount of moisture, which may be due to insufficient drying, or moisture picked up when the sleeve is rammed into a green-sand mould which may stand some time before casting (Fig. 3.20).

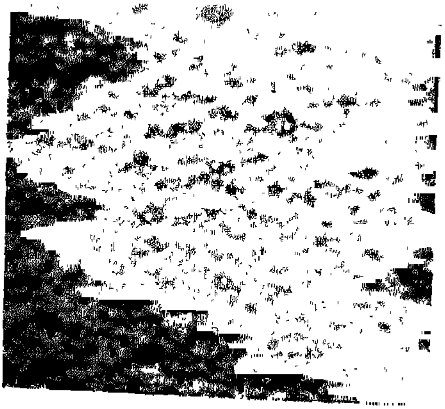


FIG. 3.20. *Structure of foamed plaster sleeve.*

Results comparing the efficiency of foamed-plaster sleeves and exothermic sleeves were given to the Brassfoundry Productivity Conference organized by the Association of Bronze and Brassfounders in 1952, following the return of the Brassfoundry Productivity Team from America; and the usefulness and economy of foamed plaster sleeved risers was clearly established. These factors have since been further proved by experience in many non-ferrous foundries, where it has been found that the use of foamed plaster insulating sleeves has enabled individual casting yields to be increased from 50 per cent or less to as high as 89 per cent.

An important point is that whatever form of feeder is applied, it is necessary to cover the molten metal surface with either an insulating or exothermic compound. Figures published by Adams and Taylor have shown that a steel feeder head loses 42 per cent of its total heat by radiation from the top surface when contained in sand; copper loses 26 per cent; and aluminium 8 per cent. In insulated heads, the figures are even higher—steel 64 per cent; copper 48 per cent; and aluminium 21 per cent. At first sight this may seem incorrect, but it will be appreciated that the figures refer to the *proportion of total heat* which is lost to the atmosphere. In other words, if heat is prevented from escaping by conduction through the side walls, a higher percentage will escape from the top surface over a longer period and the solidification will still be slower in insulated feeder heads. To obtain the maximum benefit, therefore, it is necessary to stop all possible heat loss—hence the necessity for the surface cover. It will be noted that the higher the metal temperature, the greater the radiant heat top loss, and this is readily understandable.

The limiting factors to the use of foamed plaster insulating sleeves are: (1) pouring temperature; (2) the temperature at which the metal fills the sleeve, and the resulting temperature differential between feeder and casting. Plaster sleeves will stand up to casting temperatures of 1,200 deg. C., which is adequate for most non-ferrous alloys excluding Monel and high-nickel alloys. The second consideration is the more important one in practical application. Where it is possible to fill the sleeve with hot metal direct from the crucibles after pouring the casting, this will ensure an adequate temperature differential and there will be no doubt about the effectiveness of feeding. Where this is not possible, and the metal filling the feeder head passes through the mould and loses super-heat, much would depend on the actual temperature in relation to the freezing point of the alloy. Although at the moment of completing the pour, the metal in the feeder may be a little lower in temperature than the metal forming the casting in the mould, the temperature differential will rapidly swing the other way due to the much more rapid cooling of the casting sections. The plaster sleeve requires to retain the feeding-head metal fluid only for a minute or so longer than it takes the casting to solidify, to be fully effective; providing of course that there is reasonably progressive solidification back to the mass which requires feeding, and the feeder is situated close enough to it to retain a liquid connexion with it. In these circumstances, the plaster sleeve will do all that is necessary, and an exothermic sleeve which allows the feeder-head metal to remain liquid for 10 to 15 minutes after the casting has set cannot do more.

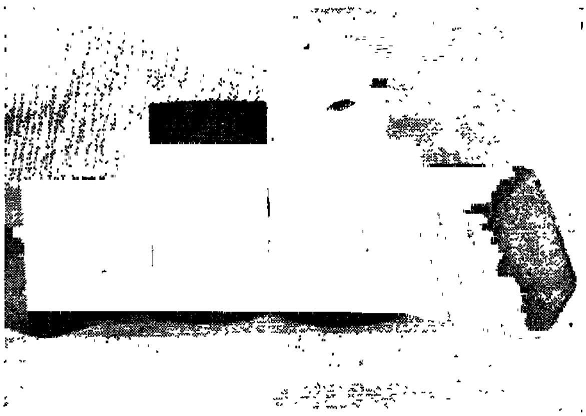


FIG. 3.21. *Various exothermic feeder shapes.*

If there is any doubt that the plaster sleeve may not have a sufficient temperature differential during the feeding period, this can be assisted by the use of an exothermic hot-topping cover instead of an insulating powder cover, but one or the other must be used. When it is doubtful whether a foamed-plaster sleeve will be effective even when assisted by an exothermic cover, then an exothermic sleeve should be used (Fig. 3.21). The extra cost of the exothermic sleeve can be regarded as an insurance that the feeding will be adequately performed in a difficult case.

The exothermic sleeve can show an advantage in some cases, where the volume of the metal in the riser or feeding heads can be further reduced, and the higher cost of the sleeve against a plaster sleeve can be offset to some degree by this.

Where the CO_2 process is in use, it is possible to obtain mouldable exothermic materials which have their own silicate bond and can be hardened with CO_2. Exothermic sleeves can also be obtained as ready-made shapes.

The correct grade of exothermic materials for any particular alloy can be selected from proprietary ranges with varying ignition and burning characteristics. The use of either plaster or exothermic sleeves increases the first cost of the casting, but the ultimate result is economically advantageous as they give sound, fully fed castings, which might not be possible otherwise. Secondly, it is possible to reduce materially the weight of the feeder or feeders in relation to the casting weight, i.e., to increase the yield from whatever may be the normal ratio (say, 50 per cent or less) to about 90 per cent. This, again, results in lower fettling costs, less metal loss, and lower melting costs.

Chapter 4

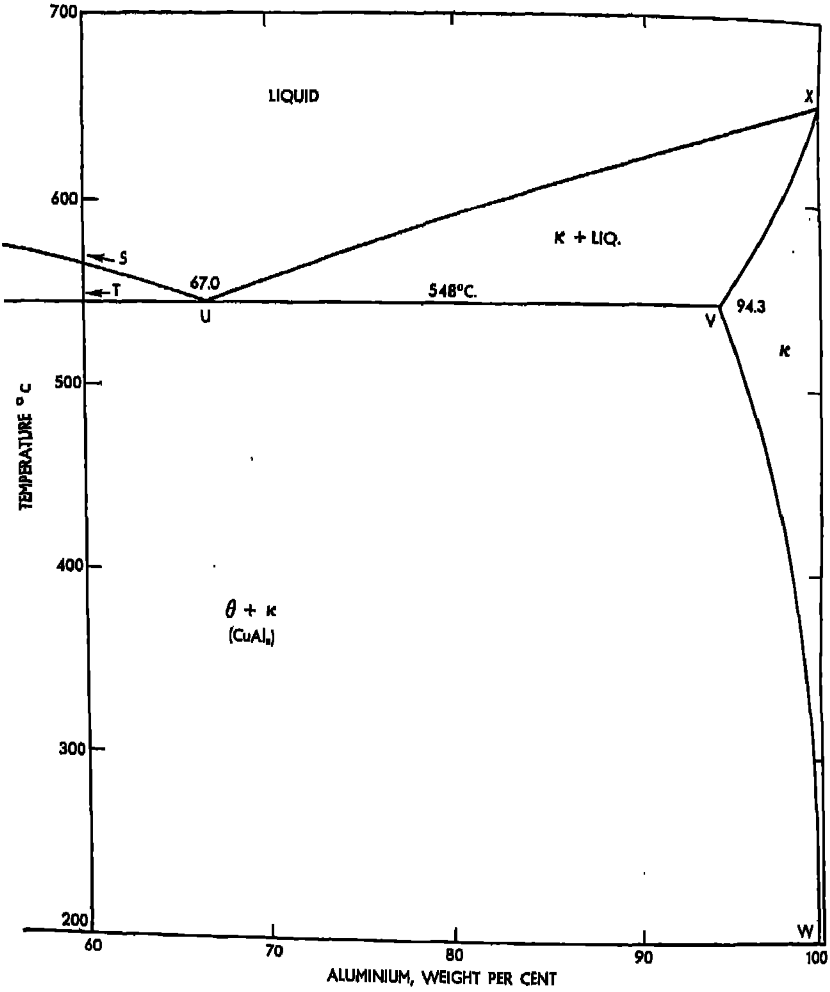
ALUMINIUM ALLOYS

THE early alloys of aluminium were low-strength, usually with zinc and copper, and their use as castings in engineering was mainly for such items as crankcases, covers and similar lightly-stressed parts. These alloys were not always satisfactory, because at elevated temperatures the mechanical properties and creep values are low. The foundation of modern heat-treatable alloys was laid by Wilm in 1907 with the discovery of Duralumin, which is an alloy of aluminium with 4 per cent copper and small amounts of magnesium and manganese. In 1909 Wilm made the further discovery that almost any alloy of aluminium containing copper and a little magnesium had the property of slowly increasing in strength and hardness after appropriate heat treatment. This very important discovery of age-hardening was made by chance, and no explanation was available at that time, or indeed for many years afterwards.

The rapid development of high-strength aluminium alloys dates from the First World War, with the evolution of Y-alloy for internal-combustion engine pistons. This is an alloy of approximately 4 per cent copper, 1·5 per cent magnesium and 2 per cent nickel, and is still a widely-used composition. It has been elaborated in the course of time and is the basis of improved high-strength compositions. With the development of aviation since 1918, coupled with the greatly increased production of aluminium and magnesium alloys, a large number of light alloys has come into use for various purposes. Most of these are covered by British Standard specifications, and the most commonly used casting alloys in general use are covered by B.S. Specification 1490: 1955.

EFFECT OF ADDED METALS

The elements commonly added to aluminium are copper, silicon, magnesium, nickel, manganese and zinc. Small amounts of titanium, cobalt, cerium and columbium are added to certain alloys to impart special properties. The addition of hardeners such as copper, silicon and magnesium improves the tensile strength and casting properties. More than double the strength of pure aluminium can be obtained by alloying with other metals, but at the expense of ductility. With the correct heat-treatment of suitable compositions, further considerable improvement in



Point	S	X	T	U	V	W
°C	591	660	548	548	548	200
Al%	46·5	100	47·5	67	94·3	99·8

FIG. 4.1. *Aluminium-rich portion of the system aluminium-copper. (From the Institute of Metals annotated equilibrium diagram No. 4.)*

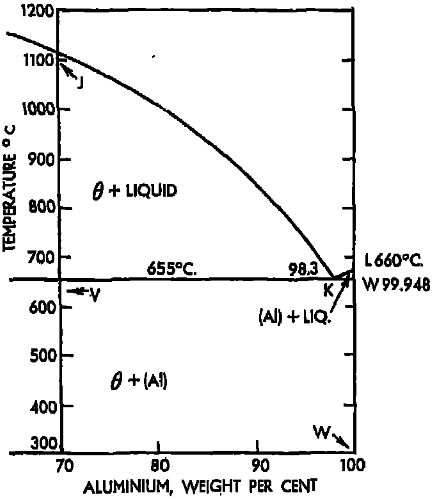


FIG. 4.2. *Aluminium-rich portion of the system aluminium-iron. (From the Institute of Metals annotated equilibrium diagram No. 13.)*

mechanical properties can be achieved.

Copper.—Copper, silicon and magnesium are the most important of the elements added to aluminium. With the exception of the aluminium-silicon series, all the high-strength aluminium alloys contain copper as one of the chief alloying elements. The relationship of copper to aluminium has, in fact, been likened to that of carbon in steel. To understand the effect of copper additions, it is necessary to refer to the aluminium-copper equilibrium diagram (Fig. 4.1). Under equilibrium conditions 5·7 per cent of copper enters into solid solution in aluminium at 548 deg. C., but under 0·2 per cent remains in solution at atmospheric temperature, copper aluminide ($CuAl_2$) being precipitated in submicroscopic form. The solubility of copper at elevated temperatures and subsequent precipitation in submicroscopic form explain the improved mechanical properties of the heat-treatable copper-aluminium alloys.

Magnesium.—The presence of magnesium profoundly affects the properties of aluminium alloys, and therefore it is an important constituent although it may only be present in quite small amounts. Silicon is invariably present in aluminium and its alloys, even when not intentionally added, and magnesium and silicon form the compound magnesium silicide (Mg_2Si) which, like copper aluminide ($CuAl_2$), is also an important precipitation-hardening constituent. The equilibrium diagram for aluminium and magnesium silicide resembles the equilibrium diagram of the copper-aluminium series inasmuch as the solubility of magnesium silicide is increased to about 1·6 per cent at 580 deg. C., but falls to under 0·5 per cent at atmospheric temperature.

Iron.—Fig. 4.2 illustrates the aluminium-iron equilibrium diagram. Iron does not enter into solid solution in aluminium, and the structures are eutectiferous, consisting of aluminium and the compound $FeAl_3$. As all aluminium alloys contain iron (most specifications allow up to 0·6

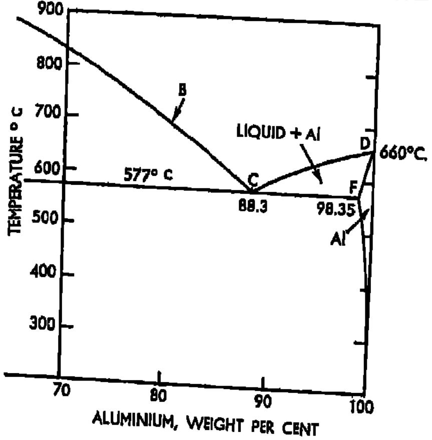


FIG. 4.3. *Aluminium-rich portion of the system aluminium-silicon. (From the Institute of Metals annotated equilibrium diagram No. 16.)*

to 0·7 per cent as permitted impurity), the resulting $FeAl_3$ constituent can be distinguished in the structure of most aluminium alloys.

Silicon.—This is a valuable addition to aluminium, either as a straight alloy to the extent of between 11 and 14 per cent, or as an addition in small amounts with other metals. A portion of the equilibrium diagram is shown in Fig. 4.3, and it will be noted that the solid solubility at normal temperatures is only 0·1 per cent. A eutectic is formed at approximately 11·7 per cent silicon, and below this amount the structure consists of primary aluminium plus eutectic (Fig. 4.5) whilst above it is composed of eutectic with amounts of free silicon according to the percentage present.

Where aluminium-silicon alloys are cast, so-called "modification" becomes necessary. This is because above 8 per cent silicon, the eutectic structure becomes exceedingly coarse when sand-cast, resulting in poor mechanical properties and particularly in low ductility. Treatment of the alloy at a minimum temperature of 750 deg. C. with either sodium salts or metallic sodium results in a fine dispersion of silicon with considerable gain in mechanical properties. Sand-cast untreated alloy is illustrated in Fig. 4.4 which shows crystals and needles of free silicon; and a fully modified structure is shown in Fig. 4.5 where the structure consists of dendrites of almost pure aluminium in a very finely dispersed aluminium-silicon eutectic.

To produce a fully modified structure it is necessary to make an addition of 0·10 to 0·15 per cent metallic sodium, to result in the necessary sodium content of approximately 0·02 per cent. This is an amount which will give satisfactory modification. Sodium can also be introduced by reduction from modifying salts, which are a mixture of sodium chloride and fluoride. Once the sodium has been added, the amount in the alloy does not remain constant, but decreases on standing because of volatilization and oxidation. Consequently the aim is to introduce a slight excess to allow for the loss which takes place during the waiting period to eliminate

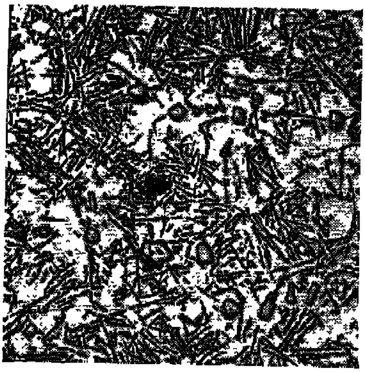


Fig. 4.4. *Structure of sand-cast unmodified LM6 alloy, showing crystals and needles of fine silicon.* × *100 diameters.*

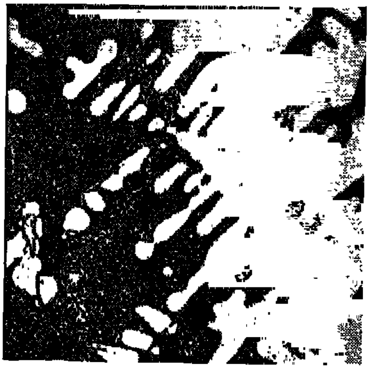


Fig. 4.5. *LM6, an aluminium-silicon alloy, showing "modified" structure containing primary dendrite of aluminium and fine aluminium-silicon eutectic.* × *100 diameters.*

gas, and to adjust to the desired casting temperature. The waiting period is desirable to permit churned-in sodium vapour and dissolved hydrogen to be eliminated before pouring; and to facilitate this, it is necessary to remove the oxide film by covering the surface with a suitable cover flux.

While the equilibrium diagrams for single additions to aluminium are in themselves relatively simple, it will be appreciated that the majority of aluminium alloys are highly complex, and many contain constituents in the structure which are not always easy to identify. A series of typical photomicrographs of commonly used aluminium alloys has been published which is of considerable help in identifying the various constituents, as these and the etching technique to reveal them are fully described. (See *Typical Microstructures of Cast Metals*, published by the Institute of British Foundrymen.)

The heat-treatable alloys usually contain two or more metals of varying solubility in aluminium, and are capable of forming intermetallic compounds either with aluminium or with each other. In a simple case of an alloy of aluminium and copper, as already mentioned, aluminium at about 500 deg. C. will (given sufficient time) take over 4 per cent of copper into solid solution. If the alloy is quenched from this temperature, the excess copper above the amount soluble at atmospheric temperature is retained as an unstable supersaturated solution. Even at ordinary temperatures a slow precipitation takes place, the effect being known as spontaneous age-hardening. From a practical point of view, the best properties are consistently obtained after quenching, by re-heating to some temperature usually not exceeding 180–200 deg. C., when sub-microscopic particles of the eutectic are precipitated. It is the particular dispersion of precipitated copper aluminide ($CuAl_2$) and other similar compounds such as magnesium silicide (Mg_2Si) which give enhanced strength and hardness to aluminium alloys when correctly heat-treated.

MELTING PRACTICE

A little-appreciated fact, to which Newsom has drawn attention, is that it takes approximately the same amount of fuel to melt 200 lb. of aluminium alloy poured at 650 deg. C. as to melt 650 lb. of 88/10/2 gunmetal poured at 1,150 deg. C. The reason is the high specific heat and latent heat of fusion of aluminium and aluminium alloys.

In a similar manner to the bronzes, as indicated in Chapter 3, aluminium and its alloys are capable of absorbing hydrogen when molten. Hydrogen is derived from the products of combustion and water vapour in the furnace atmosphere, the solubility in aluminium increasing as the temperature is raised and being rejected from solution as the temperature falls. The solubility of hydrogen is taken to be 1 cu. cm. per 100 gm. at 700 deg. C.; 0·69 cu. cm. per 100 gm. at the freezing point, and falling to 0·036 cu. cm. per 100 gm. when the aluminium has become solid at the same temperature. The principal source of hydrogen is from water vapour in the furnace gas and surrounding air. The molten metal dissociates water vapour and the oxygen combines readily with aluminium to form aluminium oxide, whilst the hydrogen goes into solution in the metal, being released again on solidification; and when severe, resulting in the type of defect known as "pinholing" (Fig. 4.6).

Degassing.—Pinholing was such a prevalent defect in the early use of aluminium alloys as almost to be accepted as inevitable in castings. Research was carried out on methods of eliminating gas, and it is now well known that chlorine, volatile chlorides, fluorides or nitrogen, when bubbled through the molten alloy, will remove dissolved gas. Any gas which is not soluble in aluminium can be used to remove hydrogen by diffusion when it is bubbled through the liquid metal. Chlorine, much used in early days, is now rarely used; and the practical degassing of aluminium alloys under foundry conditions is achieved either by the use of solid proprietary degassing agents mainly based on hexachloroethane, or by the use of nitrogen from cylinders.

The usual procedure to obtain gas-free metal in plumbago or carborundum crucibles consists of first heating the furnace to a high temperature with the burner set at the maximum. The metal is then charged into the crucible and when the melting is proceeding satisfactorily the burner is shut off and the furnace closed up. With experience, the correct temperature will be reached by means of the residual heat in the furnace when closed up. The temperature should reach 740–750 deg. C., and the metal can then be degassed by whatever method is preferred.

To avoid any possibility of grain growth, it is usual to degas with solid types of degassers which incorporate a degree of grain refinement, which then ensures better feeding and optimum mechanical properties.

Gas-content indication.—A number of foundries use the Straube-Pfeiffer vacuum solidification apparatus for indicating the gas content of a melt prior to casting. The test consists in withdrawing a test sample from the crucible or furnace and allowing this to solidify under reduced pressure. The gas bubbles which are trapped on solidification are considerably enlarged due to the reduced pressure, and a magnified indication of the gas porosity is therefore obtained. The pressure under which the test is carried out is between 20 and 50 mm. of mercury, according to the sensitivity desired.

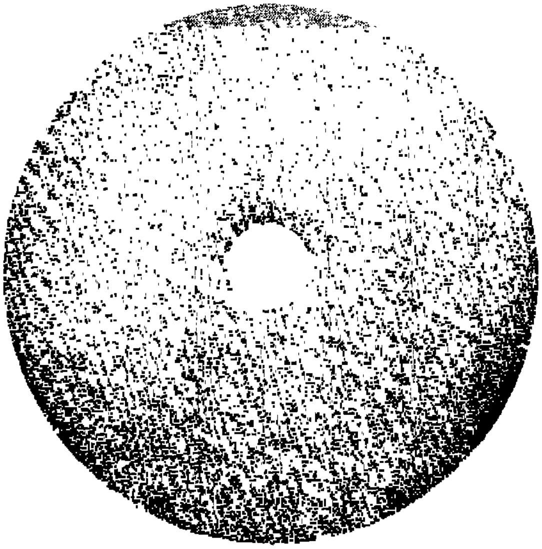


FIG. 4.6. *Aluminium alloy showing the effect of gross gas content, known as "pinholing." (Original approx. 4 in. diameter—reduced in reproduction.)*

The practical apparatus for carrying out the Straube-Pfeiffer test is mounted on a trolley which can be taken to the furnace where the test is required. The apparatus consists of a vacuum pump and a chamber where the pressure can be immediately lowered to the level required, and in which the solidification of the test sample takes place under observation through a plate-glass window.

A qualitative estimate of the degree of "gasiness" of a melt can be obtained by watching the amount of gas rejected from the top surface of the solidifying alloy in the test crucible. A more positive indication is obtained by sectioning the test block after solidification, and Fig. 4.7 illustrates the progress of degassing and grain refining. Quantitative results for record purposes can be obtained when required by determining the density of the test blocks after solidification.

Another apparatus for the direct measurement of hydrogen is known as the Telegas hydrogen-content meter. Developed and patented by Ransley, its principle is to establish equilibrium between the hydrogen content of the metal and a small quantity (2 ml.) of nitrogen circulated through it and through the apparatus. The hydrogen content of the circulating inert gas is then measured by a thermal-conductivity meter known as a katharometer.

Care should be taken to avoid over-heating and contamination of the metal during melting (either with gas or metals such as iron) not because degassing is inefficient, but because of the formation of aluminium oxide which also accompanies gas absorption. Gas can easily be removed, but aluminium oxide is difficult to remove, and a high oxide content can be a cause of scrap. Contrary to bronze-foundry practice, where a pronounced oxidizing atmosphere is advantageous, only a slightly oxidizing atmosphere is desirable for light alloys. As with bronze-foundry practice, the state of combustion can be approximately judged with oil- or gas-fired furnaces—a colourless flame denoting oxidizing conditions and a yellow-tinged flame denoting slightly reducing conditions. If necessary, the zinc rod test can be used as described in the previous chapter.

Furnaces.—Although iron crucibles were often used as holding crucibles for die-casting in the earlier days of aluminium founding, they appear to have fallen out of favour and are now rarely found in use. An argument against their use is the danger of iron contamination, especially where the alloys contain silicon. If the danger is realized, and the crucibles are kept clean and coated with a suitable dressing, the risk of iron contamination is very small. With any type of crucible, when the burner is shut off, openings in the base of the furnace should be closed as otherwise considerable oxidation of the crucible will result, owing to air being drawn in.

Practically all types of furnaces found in the non-ferrous foundry are used for melting light alloys. In the smaller jobbing non-ferrous foundry, the coke-fired pit furnace and semi-portable forced-draught furnace are often used, but these furnaces are not ideal for aluminium owing to the difficulty of controlling the temperature.

The bale-out furnace is a case where the metal is not exposed to the products of combustion, because gases are taken to the exhaust outlet without passing over the metal in the crucible; but where melting is done in crucibles in either oil- or coke-fired furnaces, a protective covering of a suitable flux cover is desirable. Suitable protection is even more essential in the case of open-hearth furnaces with direct-flame melting. Aluminium oxide forms on all molten metal surfaces and is a good protection against further oxidation. Whether this is aided by a cover flux or not, stirring or churning of the surface should be avoided. Aluminium oxide retards the absorption of gas from the outside if left as an intact covering. It can also retard the passage of gas to the atmosphere and therefore tends to retain gas which the alloy may have absorbed during melting. One method of degassing is to allow a bath of molten metal to stand quiescent for a period with a flux covering which allows gas to diffuse to the atmosphere when the burners are shut off; but this method of degassing is limited because of the time involved and because of the loss of temperature during the standing period.

In the die-casting foundry, the bale-out type of melting and maintaining furnace is popular for repetition work where quantities of molten metal are required at frequent intervals throughout the working day. Frequently the bale-out type of furnace is fed from a bulk melting furnace which is usually of the semi-rotary cylindrical type. Metal is tapped into a carrying ladle from which it is transferred to the bale-out furnace. The basin-shaped crucibles in the maintaining furnace are conveniently accessible for the various operations of degassing and modifying which are necessary.

From a quality point of view, the low-frequency induction furnace is attractive, particularly where continuous operation is required; but for a number of practical reasons this type of furnace has not yet come into general use in foundries.

Foundries rarely require more metal for a single cast than can be readily provided by one or more tilting furnaces, but where large quantities are required (as for ingot manufacture), 10-ton batches are melted in horizontal rotary cylindrical oil-fired furnaces. Larger amounts, say 20 to 25 tons, are melted in static open-hearth furnaces.

METAL LOSS

A consideration of methods of melting leads to the question of melting loss. This can vary considerably from foundry to foundry and is dependent on the type of material charged—whether it is clean and free from dirt, oil or oxide, its ratio of area to mass, the type of furnace used, the temperature charged, the time in the furnace and the treatment carried out.

Any treatment, such as degassing, modification, or particularly the removal of magnesium, increases melting loss. The question of total metal loss is important economically. If an accurate check is made over a period of six months or a year, taking the total weight of metal bought in and the total weight of fettled castings going out, and allowing for stocks of metal at the beginning and end of the period, the discrepancy may be surprising. Even where it is known that the average melting loss apart from individual melts does not exceed 2 per cent, the overall foundry metal loss in a die-casting foundry may reach a level of 9–10 per cent.

One of the main factors to be taken into account is the as-cast weight ratio to the fettled weight ratio, for this is the basis of the overall melting loss. For sand-casting, the ratio may average 2 to 1, which means that the weight of metal melted will be twice that of the final fettled weight of castings. Without allowing for the remelting of any casting scrap which may be produced, or any other losses, this means that all metal entering the foundry is virtually melted twice before going out as a casting. The overall melting loss, calculated on metal entering the foundry, is therefore at least twice the average loss on individual melts.

To illustrate the point, let us take the case of a foundry which has to make a particular casting having a fettled weight of 50 lb., and where 100 lb. of metal must be melted to cover the requirements for runners, ingates, risers, and the feeder heads. If 100 lb. of metal melted produces a fettled casting 50 lb., and 47½ lb. of runners, risers, heads etc. is available for the next melt, then the direct melting loss is 2½ per cent. The 47½ lb. of foundry scrap returns with 52½ lb. of new metal to form the charge for the next casting, and this is repeated. If 1,000 castings are made, then 52,547½ lb. of metal will have been melted, from which 50,000 lb. of castings will have been produced plus 47½ lb. of runners and risers from the final cast made. There is then a deficiency of 2,500 lb. of metal which is equivalent to a metal loss of 4·75 per cent.

In gravity die-casting the ratio may be greater still; 3 to 1 is a usual figure, and melting losses are higher due to metal being maintained at the casting temperature for long periods with frequent skimming. The true melting loss in such circumstances may be as much as 9 per cent. There are other obscure sources of metal loss in a sand foundry which may bring the overall foundry metal loss to 6 per cent or over, and 9–10 per cent in a die-casting foundry; such figures are by no means unusual. Even these reserved figures represent a considerable loss in a year's accounts, and foundries should consider all means of reducing metal loss to a minimum.

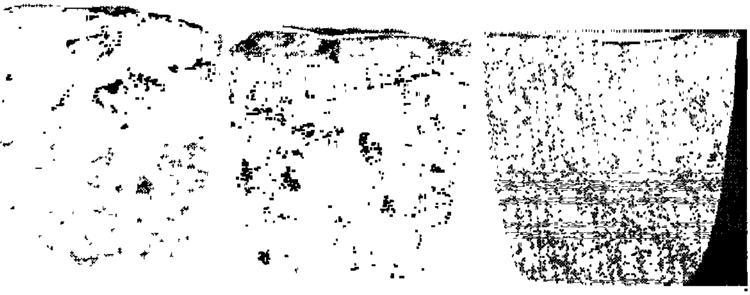


FIG. 4.7. *Sections of vacuum solidification test blocks.* Left: *a gross gas content.* Centre: *medium gas content.* Right: *fully degassed and grain-refined.*

Two practical ways should be considered: (1) The reduction of direct metal loss at the melting unit by avoiding prolonged melting or maintaining, the avoidance of unnecessary skimming or stirring, and the protection of the metal by a suitable cover flux which will prevent excessive oxidation, and which can be skimmed off without entrapping metal. (2) To increase the yield of fettled castings relative to the weight of metal melted, and reduce the ratios previously mentioned where possible.

With a suitable cover flux, the amount of metal removed when the dross is skimmed off will be small, but it is possible to reduce this still further by placing the removed skimmings in a metal container (which may simply be a steel barrow) and treating with a dross flux. This raises the whole mass of dross and skimmings to a temperature high enough to melt the entrapped metal, which drains to the bottom of the container and thence through a hole into an ingot mould. The drossing flux may be mixed with the dross on the surface of the metal before removal, or may be applied in thin alternate layers of skimmings and flux in the dross container.

Careful observance of correct temperature control, and the avoidance of unnecessarily high temperatures will also help to keep metal loss low, in addition to aiding soundness and higher quality castings with less scrap.

ALUMINIUM ALLOYS FOR CASTINGS

B.S. Specification 1490: 1955 lists 22 alloys which cover the requirements of sand, gravity-die, and pressure-die castings for general engineering purposes. L.M.1 and L.M.22 are mainly gravity die-casting alloys, LM1 being a zinc-containing alloy of medium strength used as cast. LM2 and LM24 are primarily pressure die-casting alloys. LM21 is another popular alloy used for both sand casting and gravity die-casting in the as-cast state. It is similar to LM4. LM22 is an alloy with high shock resistance used in the solution treated condition. LM3 is an aluminium-zinc-copper alloy, limited by its casting characteristics to sand castings; it develops higher strength on age-hardening from the as-cast condition than any of the other LM alloys. It has excellent machinability and little ductility.

LM4 is a universal alloy capable of producing satisfactory castings in sand, gravity-dies or pressure-dies, and is used without heat treatment, although solution treatment will improve the strength and ductility. This is a reliable, general-purpose alloy and is used in a greater amount than any other; it originated early in the Second World War when a reliable secondary alloy was required to use up Duralumin scrap and economize in the use of virgin aluminium. The composition is nominally 3 per cent copper, 0·5 per cent manganese and 5 per cent silicon, with impurity limits as specified in B.S.S.1490: 1955.

Although used mainly in the as-cast condition, the presence of a small amount of magnesium (0·15 per cent is permitted in the specification) makes LM4 alloy responsive to heat treatment. Proof stress, ultimate tensile strength and Brinell hardness can be considerably increased, but the ductility is lowered. Although magnesium is limited to 0·15 per cent, in instances where maximum elongation and ductility are required, it should be below 0·1 per cent. and preferably 0·05 per cent. If necessary, magnesium may have to be reduced by a magnesium-removing treatment, and this can be carried out in the foundry with magnesium-removing fluxes. This being essentially an oxidizing process and carried out at a high temperature, it is not very desirable, as apart from other effects it is accompanied by high metal loss, so it is preferable to specify that the alloy be supplied with a suitable low magnesium content in the first place.

Where the highest mechanical properties are required, and test bars have to be provided, it is possible to obtain improved results by modifying the silicon in the structure. Normally, the silicon is present as definite plates and crystals, and the effect of a sodium addition—as in the case of aluminium-silicon alloys—is to disperse the silicon in finer form. The effect is illustrated in Fig. 4.8, which shows LM4 alloy before modification treatment, and in Fig. 4.9 where the silicon is in fine form after treatment with sodium. This is accompanied by a slight gain in tensile strength and ductility. Modification treatment can be applied either by the use of modifying salts as a cover, or by the addition of a small amount of metallic sodium after degassing, as is usually done with aluminium-silicon alloys.

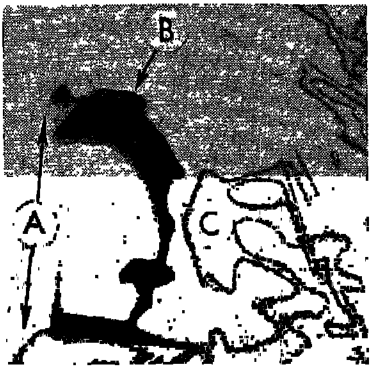


FIG. 4.8. *Structure of LM4 alloy before modification treatment, showing silicon present in the form of crystals. (A) shows the* $CuAl_2$ *constituent, (B) the complex manganese-rich crystals, and (C) is silicon.* × *650 diameters.*

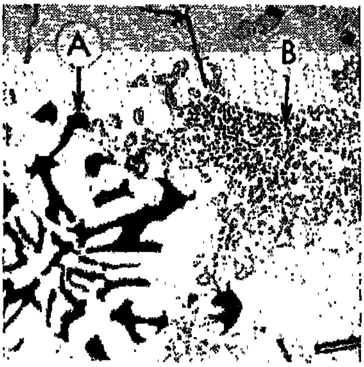


FIG. 4.9. *Structure of LM4 alloy after modification treatment, showing the silicon in finer form. (A) shows the complex manganese-rich crystal, (B) the silicon in more finely dispersed form. Straight iron-rich plate crystals can also be seen in this illustration.* × *650 diameters.*

Where treatment to remove magnesium has been carried out, grain refinement will also be desirable. This can be carried out by the addition of titanium as an aluminium-titanium alloy, or more simply and effectively by the use of grain-refining tablets based on the double salts of titanium and boron fluorides (Fig. 4.10). The effect of modification and grain-refining treatments is to improve mechanical properties and the "castability" of the alloy. The heads of two A.I.D. test bars are illustrated in Fig. 4.11; that on the left is cast in alloy which has been treated, and that on the right is untreated.

LM5 alloy contains 3–6 per cent magnesium; LM6 is the eutectic aluminium-silicon alloy (10–13 per cent silicon); LM8 and LM18 are also aluminium-silicon alloys, lower in silicon. All four are particularly good in their corrosion resistance—especially LM5 which is used where corrosion resistance has first priority, as in marine castings. LM5 is not so readily cast as LM6, and is used for sand, gravity and pressure die-castings.

LM6 is a widely used alloy which has been in general use since the 1930's. There is, however, still uncertainty regarding the correct modification of this alloy and the attainment of the specified tensile and elongation figures. Without modification, the alloy is of relatively low tensile strength and comparatively brittle, breaking through the plates of silicon with a coarse fracture. The effect of correct modification is to raise considerably

FIG. 4.10. *Effect of grain-refinement treatment.*

both the tensile strength and the elongation. The shock resistance of the unmodified alloy is very low, but high with the modified material. Modification depends upon the presence of sodium, and this can result from treatment with mixtures of chloride and fluoride salts, or from the direct addition of metallic sodium. Each method has advantages and disadvantages.

Modification is applied after degassing, for the reason that the passing of chlorine or chlorinated hydrocarbons resulting from the decomposition of hexachloroethane removes any sodium present and therefore destroys any existing modification. Modification by the use of a cover of modifying salts may be preferred because the process is less critical and therefore more foolproof. The salts cover does not introduce gas, and helps to eliminate residual gas which may still be present after degassing if this has not been properly carried out. The salts are placed on the surface of the molten alloy at a temperature of 750–800 deg. C. and stirred in at intervals over a period of 10 minutes. The disadvantage of salts modification is the crucible attack which occurs and which reduces crucible life.

Crucible attack is avoided by modification with metallic sodium, but the handling and use of loose sodium is not only hazardous in the foundry, but results in gas pick-up. The gas pick-up comes from the oil and hydroxide film which loose sodium invariably carries, although this source of gas can be avoided by the use of clean oil-and-hydroxide-free sodium packed in hermetically sealed pure aluminium containers. Even so, the excess sodium which must be added to get the required amount into the alloy, and of which a considerable amount is volatilized, has the effect of churning sodium vapour into the alloy, and with the sodium vapour resulting from the sodium loss continually taking place from the molten alloy, often results in the presence of sodium vapour holes in the final casting. These are almost certain to occur if the casting has been made without a sufficient waiting period after the sodium addition, or if the sodium addition has been excessive. Sodium vapour holes can be distinguished from ordinary gas pinholes by their almost complete circularity and their shining brightness; they are often surrounded by a microscopic area of over-modification (Fig. 4.12).

The amount of metallic sodium necessary is normally approximately 0·1 to 0·15 per cent. The exact amount under any particular foundry condition is best determined by practical tests. The amount is also affected by the size of the melt being treated and the depth of the melt, so that larger amounts will require a smaller sodium percentage than small amounts.

A treatment now used by many foundries is known as the Modegas process. This consists of a combined degassing and modification process in one operation, and has the advantage of the sodium method with its avoidance of crucible attack, yet without the disadvantage of additional gas pick-up.

LM8 and LM18 alloys are both commonly sand and gravity-die cast.

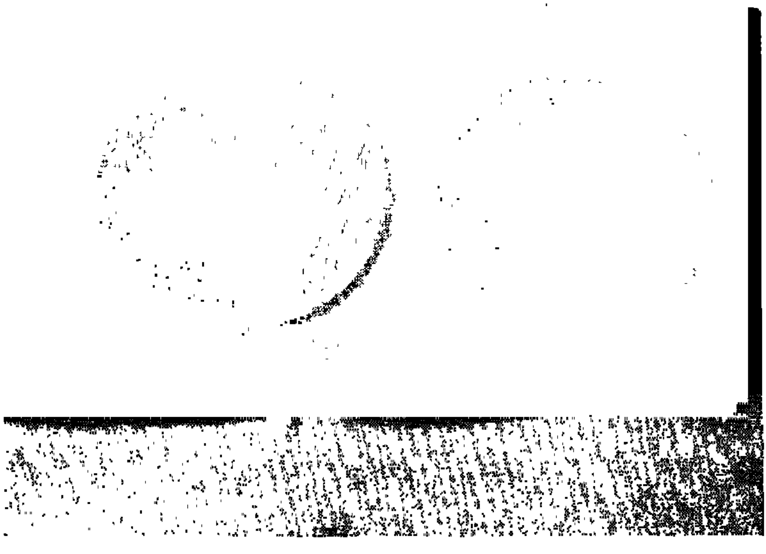


FIG. 4.11. *Effect of treatment on D.T.D. test-bar heads. Brighter cast skin and better feeding properties are shown on the treated bar (left) compared with the untreated bar (right).*

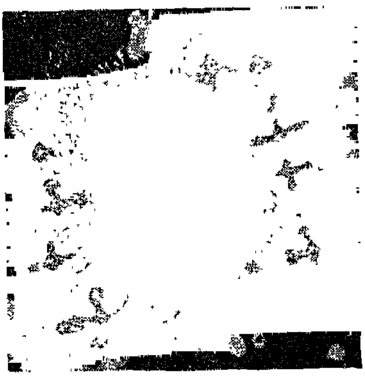


FIG. 4.12. *Structure of LM6 alloy modified with metallic sodium and showing slight over-modification, also sodium vapour hole with evidence of surrounding envelope of pronounced over-modification. × 100 diameters.*

LM8 is suitable for intricate castings which require good fluidity and pressure-tightness. Its corrosion resistance makes it suitable for applications where it may be in contact with foodstuffs or chemicals. This alloy is also capable of heat treatment which raises the fully heat-treated material to the high-strength level.

LM9 is similar to LM6, but contains a small amount of magnesium which renders it heat-treatable. Because of this, it has greater strength, the fully heat-treated condition giving a minimum of 15·5 tons per sq. in. tensile, but having little elongation.

LM10 is a 10 per cent magnesium alloy for sand and gravity die-castings where high strength and shock resistance is required. Both this alloy and LM11—another high-strength alloy—require special treatment in the foundry.

Pistons, cylinder heads and other i.c. engine components are usually made of the alloys LM12, 13, 14 and 15, their characteristics being the maintenance of good strength at elevated temperatures. These alloys are also suitable for many stressed castings subjected to temperatures up to 300 to 350 deg. C. LM14, well-known as Y-alloy, is also used for some room-temperature applications where good strength is required.

LM16 is suitable for the sand casting and gravity die-casting of rather intricate work where high strength resulting from heat treatment is required.

LM20 is a eutectic silicon alloy similar to LM6, but with greater permitted amounts of copper and magnesium which lower the ductility but improve the machinability; it is mainly gravity and pressure die-cast. LM22 has good foundry properties but is only used for gravity die-casting; in the solution-treated condition it has good strength and ductility. LM23 is an alloy used for sand and gravity die-castings in internal-combustion engines. Used in the precipitated condition (sand cast) it gives 10 tons per sq. in. tensile with 2 per cent elongation. LM7 is a similar alloy but is used without heat-treatment for general-purpose castings.

Recently introduced into this country is the American alloy 40-E, which has received official recognition under Specification D.T.D. 5008. It contains about 5·5 per cent zinc, 0·6 per cent magnesium, 0·5 per cent chromium and 0·2 per cent titanium, and gives high strength and ductility without heat treatment—minimum figures for sand castings are 14 tons per sq. in. tensile with 4 per cent elongation, and Brinell hardness of approximately 75; these figures are achieved after spontaneous age-hardening for 21 days. The corrosion resistance is good and the alloy machines well. This alloy has a long freezing range common with all other high-strength casting alloys and consequently calls for a higher degree of skill on the part of the foundryman to produce sound castings.

PREVENTION OF METAL/MOULD REACTION

Aluminium alloys containing magnesium as a definite alloying constituent require special attention during melting and the preparation of moulds which have a facing of a special sand carrying an inhibitor, because they are particularly prone to metal/mould reaction. Magnesium is liable to considerable oxidation whilst melting, and it is desirable to use a cover flux which will not only provide a protection but cleanse the alloy of oxides. Suitable flux covers are available, and should be used as directed. It will usually be necessary also to grain-refine the alloy as this considerably improves the castability. The alloy should not be heated to a temperature exceeding 750 deg. C., and after treatment for grain refinement it should be thoroughly degassed. A waiting period of at least five minutes is desirable prior to casting. Light castings should be cast at approximately 720 deg. C., medium castings at 700 deg. C., and heavy castings at 680 deg. C.

To avoid mould reaction, the facing sand will require to contain between 2 and 3 per cent boric acid, or alternatively about 2 per cent of ammonium bifluoride. Metal/mould reaction is readily diagnosed by the badly discoloured area which extends into the section from the surface and which is disclosed when the casting is fractured. The rather high shrinkage necessitates adequate feeding arrangements and suitable risers and bosses should be provided on thick sections. Chilling can also be used with advantage. Turbulence should be avoided whilst pouring by the use of choked down runners and ring runner systems with multiple ingates. The sand used for casting magnesium alloy should be kept separate from other sand in the foundry, and it is also necessary to segregate all metal scrap and keep it apart from other aluminium alloys.

Chapter 5

MELTING FURNACES

IN THE following survey of modern foundry melting furnaces, the main types are described under these headings: crucible, electric, rotary, reverberatory, converters, cupolas. In some cases, a furnace may be used for melting both ferrous and non-ferrous metals. Where it is appropriate, the particular uses of these furnaces are described.

CRUCIBLE FURNACES

The crucible process for melting metals is one of the oldest and simplest techniques. It is still used extensively in modern foundries and is likely to continue in favour, because of its initial cheapness and because the metal is melted out of contact with the fuel. Crucible furnaces are usually divided into classes according to the method of pouring the metal from the crucible, as follows: (1) lift-out furnaces, where the crucible is removed from the furnace and carried to the moulds for pouring; (2) bale-out furnaces, where the metal is ladled out of the crucible into moulds; (3) tilting furnaces, which may be of the central-axis or the lip-axis type. With lip-axis furnaces, the pouring point remains constant so that it is not necessary to move the ladle during the pour, and in suitable circumstances the metal can be poured from the furnace direct into moulds. All these furnaces can be fired by oil, coke or gas, or heated by electricity.

Lift-out Furnaces. Lift-out furnaces may be of the pit-type, or at ground level, or raised above the floor. The older pit-type is usually fired by coke, sufficient coke being packed around and above the crucibles (which are fitted with a refractory cover) to melt and superheat the charge without recoking. The fuel rests on a grate above an ash pit. Such pit furnaces are also used for crucible steel melting (see Fig. 5.1). The draught may be natural, that is, from a chimney fitted with dampers, or forced, using a small fan working at a pressure of about 2 in. or 3 in. water gauge. The latter method is preferable for closer control of heat and atmosphere. The coke space between the crucible and the pit lining should be at least 3 in. and the space between the bottom of the crucible and the firebars should be about 7 in. The lip of the crucible should be just below the level of the flue outlet. The firebars and all air inlets should be kept free from clinker to permit free entry of air, which is required for combustion and maintenance of a slightly oxidizing atmosphere.

Apart from being easier to control, oil- and gas-fired pit-type furnaces usually have a higher melting rate than the others, but impose more severe conditions on the crucibles and refractories. Crucibles vary in capacity and may hold up to 350 lb. although 100 to 200 lb. is more usual for iron or steel, and about 150 lb. for brass. Large sizes require lifting tackle for drawing the crucible from the furnace, whereas smaller crucibles are lifted with tongs by one or two men. In some cases, crucibles having an aluminium capacity of up to 400 lb. have been used in such furnaces; the advantage claimed is that the metal is subjected to the least possible disturbance and splashing in transfer from the melting unit to the actual mould.

Bale-out Furnaces. These are used where small quantities of non-ferrous metals are required at frequent intervals, as in die-casting foundries. They may be used for holding or maintaining molten metal only, but in some cases the main melting is also carried out in the bale-out furnaces. Their thermal efficiency is rather low for melting, particularly on high-temperature work, but they do provide a small self-contained unit which will handle a variety of work (Fig. 5.2).

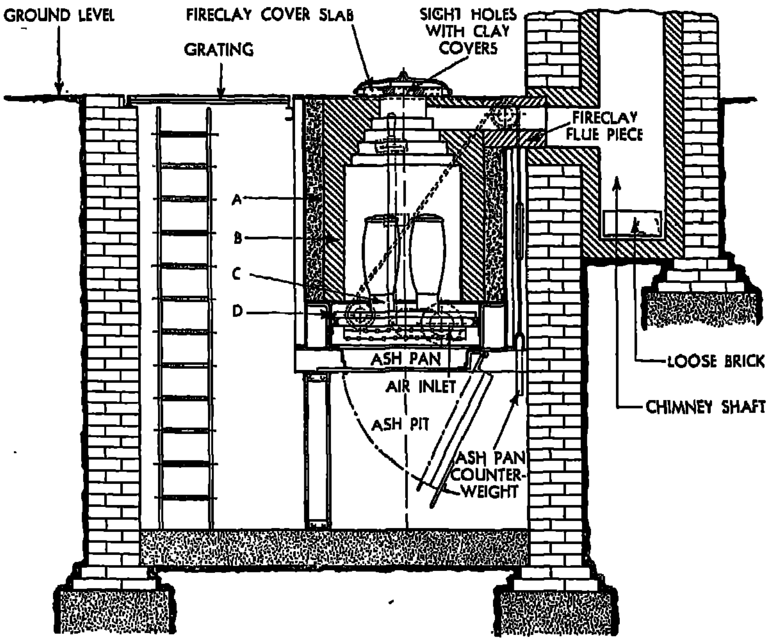


FIG. 5.1. *Sectional elevation of forced-draught type crucible furnace as used for the melting of steel. Such furnaces are usually arranged to take four crucibles. (A) firebrick outer lining, (B) special firebrick inner lining, (C) crucible stands, (D) firebars.*

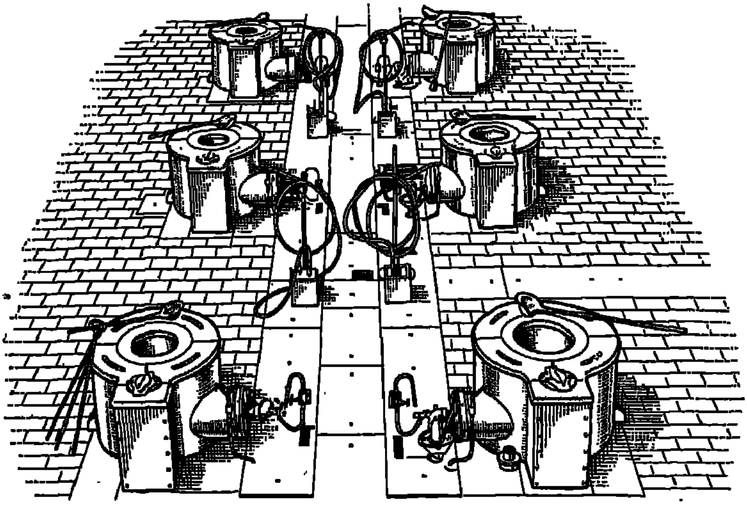


FIG. 5.2. *Battery of six oil-fired, bale-out crucible furnaces used for the melting of aluminium alloys. Each is fitted with flue controls and arranged to exhaust into an underground flue. With such a battery continuous melting can be arranged.*

Tilting Furnaces. These are mainly used where a comparatively large output of any particular alloy is needed. Like pit-type furnaces, they are heated by the combustion of coke, oil or gas. The furnace consists essentially of a mild-steel casing lined with refractory bricks or a rammed refractory lining. It is normally cylindrical, and a typical example is shown in Fig. 5.3.

In some coke-fired tilting furnaces, the grate is provided with an enclosed ash pan. Airblast is supplied through trunnions into a windbelt which surrounds the lower part of the furnace, or through ducts in a twin-walled casing to acquire some preheat. Adequate capacity for the coke is essential, especially for ferrous metals. This avoids recoking during the melt, with attendant heat losses. When starting up coke-fired tilting furnaces, a shallow fire of wood and coke is lit first, and when the coke is burning evenly around the crucible, the furnace is fully charged with coke. (Some furnaces are equipped with a gas lighting ring for starting up.) With the air at quarter blast, the crucible is brought up to red heat, then charged with metal. About 30 minutes should elapse between lighting the furnace and charging crucibles of 250 lb., and about 45 minutes for those of 10 cwt. brass capacity.

Oil- and gas-fired units are similar in design, except that no windbelt is required and a grate is unnecessary, as the crucible rests on a refractory stand. The burner is usually fixed to the furnace in such a way that firing can be continued while the furnace is tilted. This is an advantage when metal is required in small quantities and the pouring period is prolonged. Care should be taken to avoid explosions in gas-fired furnaces, especially during the lighting-up period. The accumulation of explosive mixtures of unburnt gas or inflammable vapour and air should be prevented, mainly by the use of automatic pilots or "flame failure" devices, low-pressure cut-off valves, and by ensuring that sufficient air is available at all times.

When starting up oil- or gas-fired tilting crucibles, the crucible is heated empty, gently at first, using the lowest flame the burner will provide for the first ten minutes. The rate of heating is then increased in stages until the crucible is red hot, when it should be charged at once and the burner turned full on. The time taken to reach red heat should be about 30 minutes for sizes up to 650 lb., 45 minutes for sizes to hold 10 to 15 cwt. brass or 5 cwt. aluminium, and 75 minutes for 10 cwt. aluminium capacity crucibles.

Crucibles should be charged while the furnace is vertical, using tongs

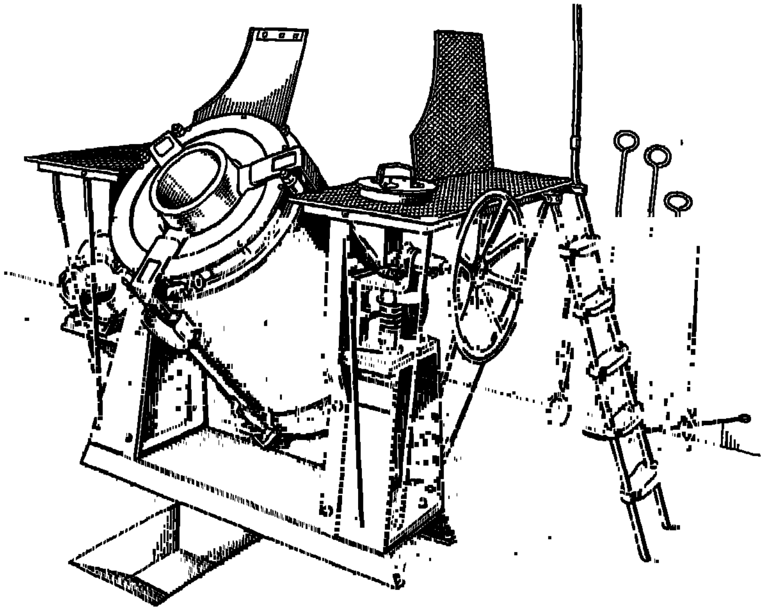


FIG. 5.3. *A coke-fired tilting crucible furnace. The furnace is tilted by turning the handwheel shown on the right. Similar furnaces fired by oil or gas are available.*

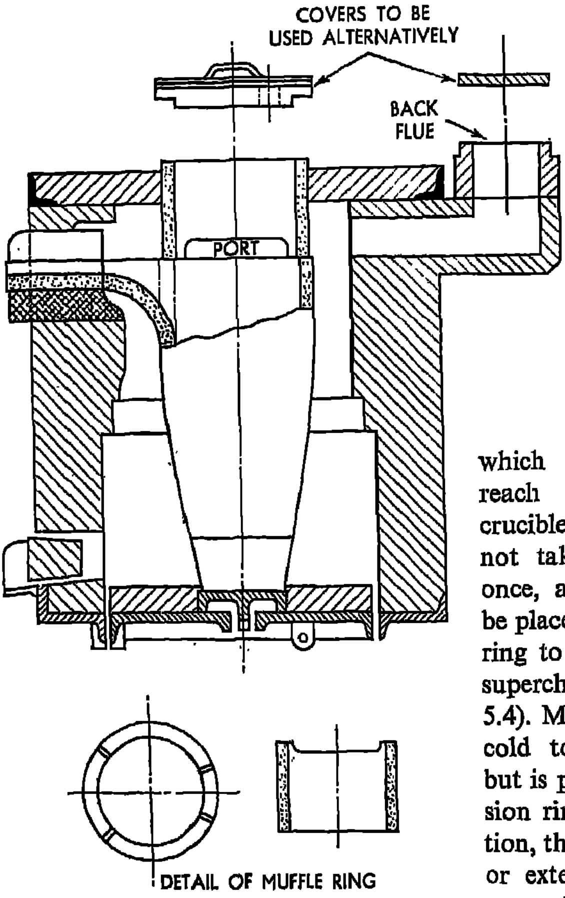


FIG. 5.4. *Supercharge preheating method, using a spouted crucible and muffle ring.*

which are long enough to reach the bottom of the crucible. If the crucible cannot take all the charge at once, an extension ring can be placed on top of the muffle ring to take as much of the supercharge as possible (Fig. 5.4). Metal is not then added cold to the molten charge but is preheated in the extension ring. To prevent oxidation, the crucible, muffle ring or extension ring should be covered with a refractory lid.

Experiments with preheated air have generally been disappointing, giving almost negligible gains in fuel economy and melting times. Indeed, it would appear that crucible furnaces have reached the stage of development where there is little scope for any marked advance on modern designs. Most development work is now directed to improving working conditions, ease of control and convenience of operation. Back-flue furnaces are being employed more widely to avoid exposing operators to the heat of the exhaust flame. Thought is also being given to the alternative processes (especially in die-casting foundries) of either melting and maintaining metal in the same unit, or employing a bulk-melting furnace in conjunction with several maintaining furnaces. The first method probably gives better fuel economy, but the second gives improved flexibility and more scope for dealing with alloys which have to be modified or otherwise treated.

TABLE 5.1
RELATIVE THERMAL EFFICIENCIES OF VARIOUS TYPES OF FUEL-HEATED CRUCIBLE FURNACES
(after F. W. Rowe)

Type of Furnace	*Thermal Efficiency*
Coke-fired, crucible pit-type, natural draught	3–7%
Coke-fired, crucible tilting type, forced draught	8–13%
Oil- or gas-fired crucible tilting furnace	7–18%

Table 5.1 gives the relative thermal efficiencies of the main types of crucible furnace.

ELECTRIC FURNACES

Electric furnaces are being increasingly used for metal melting and many new and improved types of furnace have been introduced in recent years. It is, however, important to assess their relative importance, and the various types will be described in the order of their industrial significance. Electric melting furnaces fall into three main groups: (1) arc furnaces; (2) induction furnaces; (3) resistor furnaces.

ARC FURNACES

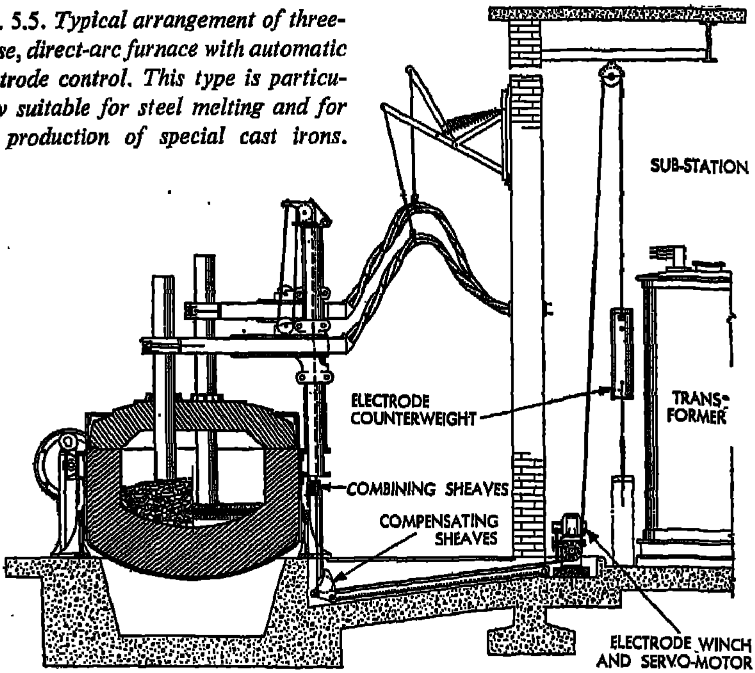
Arc furnaces represent by far the majority of applications, including the melting of steel, grey iron, brass, bronze and gunmetal, as well as many nickel alloys. There are two main types of arc furnace, the direct arc and the indirect arc.

Direct arc furnaces are so called because an arc is struck directly between the electrode and the metal to be melted. The electrodes are of graphite or amorphous carbon, and the furnaces are either single-phase units for very small furnaces (under, say, 2 cwt. capacity) or, more generally, three-phase units with three overhead, vertically disposed electrodes suspended over what is normally a bowl-shaped refractory hearth. Practically all modern furnaces are circular in plan, with refractory sidewalls and a dome-shaped roof provided with holes for inserting the electrodes, as shown in Fig. 5.5.

In the three-phase furnace, which is now made in holding capacities of up to 150 tons (of steel), the electrodes are arranged at the apices of an equilateral triangle. Where they pierce the roof, water-cooled collars, or glands, are disposed so as to cool the electrode at this point and seal the opening, thus obviating an excessive chimney effect.

The furnace is housed in a robust steel shell, on one side of which are mounted three columns on which run the arms carrying the electrodes.

FIG. 5.5. *Typical arrangement of three-phase, direct-arc furnace with automatic electrode control. This type is particularly suitable for steel melting and for the production of special cast irons.*



These not only support the weight of the electrodes, but also carry the conductors and water-cooling pipes to the electrode clamps. These take the form of a split-hinged, water-cooled collar, tightened by means of a screw or a hydraulic or pneumatic piston. Sometimes they are not hinged, but are made as a solid collar, the electrode being secured in the collar by means of a wedge, either mechanically or pneumatically released. The electrodes are raised and lowered on their masts either by electric motors or by hydraulic rams. In the early furnaces electrodes were either raised by hand or by hand-control of the electrode motors. Lowering the electrodes shortens the arc and increases the power input, and vice versa. Control of power input is now done automatically, and when electric motors are used, the starting and reversing is controlled by the current flowing through the electrode and by the voltage between the bath and the electrode.

There are different methods of automatically controlling power input, but the most popular system uses a Ward-Leonard type of control in which D.C. generators operate the D.C. electrode motors, the generators being controlled by the current-voltage flowing in the electrodes. This gives an amplification effect, because if the deviation from a predetermined setting is large, then the motor speed is fast to restore the equilibrium, and vice versa. Hydraulic control normally uses a servo-cylinder and piston directly connected to the electrode arms. In principle, hydraulic regulators consist of an electric element sensitive to current and voltage, and a device (such as a magnetically operated valve) to convert the electrical signals into a corresponding change in oil or water pressure.

Practically all furnaces used for melting are of the tilting type, usually mounted on rocker trunnions situated under the furnace, or at the sides of the shell. At right angles to the electrode arms is a pouring spout and diametrically opposite is a charging or operating door. Small furnaces, say up to 1½ tons in capacity, are charged through this door by means of a chute or by hand, whereas nearly all larger furnaces are top charged by removing the roof. As has been explained, the roof is a domed refractory brick structure set in a circular steel channel, normally called the "roof ring." In the case of top-charging furnaces, this roof is lifted and moved away so as to leave the top of the furnace open for charging. The roof can be moved away laterally by means of a gantry (after the electrodes have been raised out of the furnace), or it can be pivoted and swung aside; once the furnace top is opened the charge is inserted by means of a drop-bucket (Fig. 5.6.).

The operating door on a top-charged furnace is used for making alloy or slag additions, for rabbling the molten metal and for removing the slag if necessary. The furnace can usually be tilted backwards to assist this operation. Some furnaces are made nose-tilting, especially those installed in foundries where it is sometimes necessary to pour into small ladles or hand shanks. They are pivoted on the axis of the pouring spout, the furnace being lifted bodily by hydraulic rams. In this way the height of the pouring point remains constant.

All arc furnaces of any size are designed for connexion to a high-tension supply. The electrical equipment consists of a high-tension circuit breaker and a step-down transformer, the secondary side of which is provided with a range of voltage tappings to suit the melting and refining conditions in the furnace. The highest voltages, 180 to 450, are used for melting and the lower voltages, 80 to 160, for refining or maintaining temperature. Generally, the voltages used increase with the furnace size, so that a melting voltage of 450 would be used on the largest furnaces and one of 180 on furnaces of two to three tons. There are a series of alternative voltages for every furnace installation and the voltages are selected by a tapping switch. A variable reactor is also built into the furnace transformer, this being essential to give arc stability and also to damp current surges. A high reactance is used for melting and this is progressively reduced with voltage until the external reactance is cut out during refining.

Direct arc furnaces are either acid- or basic-lined, depending on the

FIG. 5.6. *Roof removed from electric-arc furnace to facilitate bucket charging.*

melting operation to be carried out. A basic lining consists of a hearth made of a rammed dolomite mixture, or of magnesite. This basic lining can include the side walls, but sometimes the upper side walls in a basic furnace can be of silica; and the roof is almost invariably made of silica brick. Basic linings are used for steelmaking when sulphur and phosphorus removal are required and are generally recommended for high-alloy steels, such as stainless and manganese steels. They are also used for copper and for nickel alloys. Acid linings consist entirely of siliceous materials and are restricted to the melting of cast irons and the production of steel castings from scrap requiring no removal of sulphur and phosphorus.

A recent development has been the introduction of electromagnetic stirring by mounting a coil underneath the hearth of the furnace. This makes possible controlled stirring of the molten metal and also helps in the removal of slags from the furnace bath. This method, however, applies more to large furnaces and is rarely used on the smaller sizes usually installed in foundries.

Indirect arc furnaces are so called because the arc is struck between two carbon electrodes and is therefore independent of the charge, which is heated indirectly by radiation. Many of the older arc furnaces were of this type, but the only surviving representative of this kind of furnace is the rocking arc furnace, which is quite widely used for melting of special cast

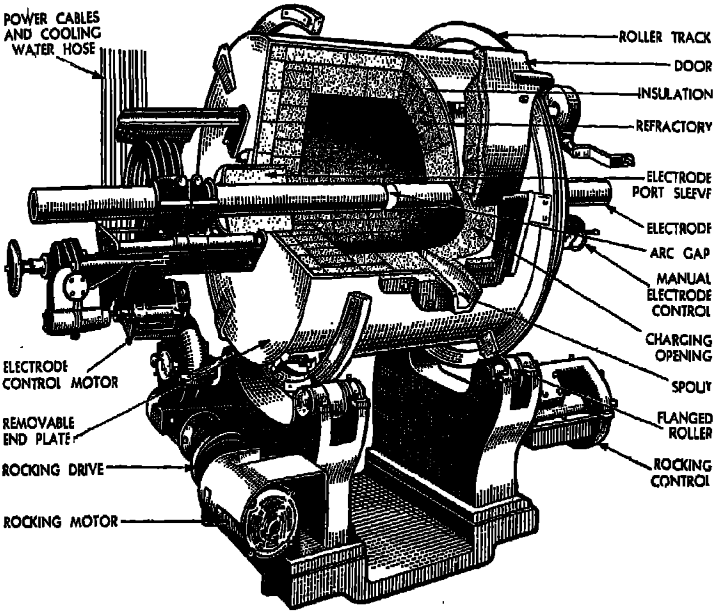


FIG. 5.7. *Part-section view of indirect rocking-arc furnace. During operation the furnace is rocked by the motor (bottom left) in order to distribute the heat as rapidly as possible. Furnaces of this type are usually designed to melt and superheat a charge in one hour.*

irons, for bronzes and gunmetals, and occasionally for nickel alloys. It consists of a cylindrical or spherical refractory-lined shell with two graphite electrodes horizontally mounted, striking an arc in the centre of the refractory enclosure. The shell is mounted on rollers; these are motor-driven through a reversing switch which gives the furnace a rocking motion.

A cut-away section of a typical cylindrical furnace is shown in Fig. 5.7. It will be seen that there is one charging opening, closed by a door, under which there is a pouring spout. The furnace is charged through the door after withdrawal of the electrodes, and the furnace is filled below the level of the electrodes. The automatic rocking controller is set so that rocking does not start until the charge begins to subside; alternatively, it is started with a very small angle of rock to prevent pieces falling on the electrodes and causing breakage. The angle of rock is automatically controlled so that it increases progressively as melting proceeds, so that by the time melting is complete the furnace is on full rock. This means that practically all the refractory lining is being continually washed by molten metal to distribute the localized heat of the indirect arc. The rocking motion

TABLE 5.2
ROCKING-ARC FURNACES

Typical sizes of rocking-arc furnaces for non-ferrous and ferrous melting, with transformer ratings and melting capacity

Charge Capacity		*kVA*	*kW*	*Approx. throughput per 8-hour day*
Cold metal lb.	*Molten metal lb.*			
(*a*) For a leaded gunmetal of the 85/5/5/5 type				
35	75	36	25	600 lb.
50	100	50	30	750 lb.
200	325	117	75	1·3 tons
350	500	153	100	2·0 tons
500	1,200	225	150	2·9 tons
1,000	2,200	358	250	4·5 tons
3,000	6,000	525	350	5·6 tons
(*b*) For cast iron				
35	75	36	25	320 lb.
50	100	50	30	390 lb.
200	325	150	100	1,550 lb.
350	500	190	125	1·2 tons
500	1,000	250	175	1·6 tons
1,000	2,000	530	400	3·1 tons

also ensures good mixing, and for that reason the furnace is preferred for alloy irons and leaded copper alloys.

The furnace is fed from a transformer, generally using a high-voltage supply, and has a built-in reactor to give arc stability. As it is a single-phase furnace, it is necessarily restricted in size, the largest units rarely exceeding 10 cwt., and is generally from ½ to 5 cwt. in capacity. Table 5.2 gives the power input and holding capacities for non-ferrous and ferrous melting. Copper alloys are generally melted and poured in within 30 minutes once the furnace lining is hot, while cast irons generally take about one hour per melt.

The electrodes in small furnaces are generally regulated by hand, one electrode being fixed and the other being moved inwards or outwards to keep a constant power input. The movable electrode can be controlled automatically by a motor which is started and reversed by a contact-making ammeter. The furnace is ideal for intermittent operation in a foundry, and can melt both cast irons and non-ferrous metals, but for this purpose it is advisable to keep two shells which are interchangeable to

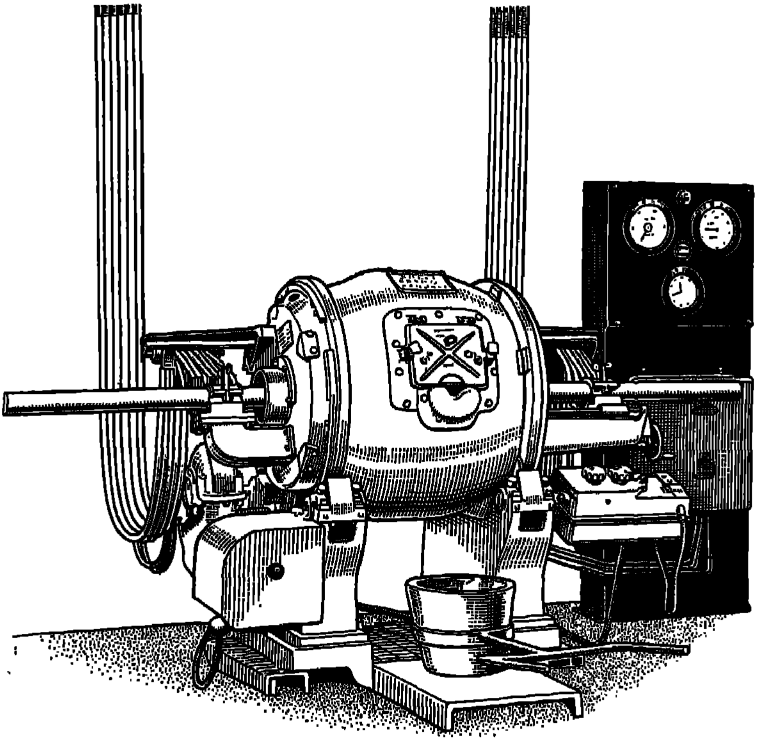


FIG. 5.8. *Indirect rocking-arc furnace for the melting of special cast irons (500 lb. capacity). The only opening (shown in the centre) is used for charging and pouring, and for slag removal.*

avoid contamination. A modern furnace with a spherical shell is shown in Fig. 5.8.

INDUCTION FURNACES

In view of the many variations in induction furnaces, it is now impossible to classify them in accordance with the frequency of the current they use. Furnaces using frequencies in excess of 500 cycles per second have a bath in the form of a cylindrical crucible and employ no internal iron cores. These are normally called "coreless" induction furnaces. In recent years, however, many furnaces of this type have been built for use on 50 cycles per second, i.e., mains-frequency supply. In the past, mains-frequency furnaces employed a melting channel which formed the closed-circuit secondary of a step-down transformer, and this is known as the "channel type" induction furnace.

Coreless Induction Furnaces. The capacity of these furnaces ranges from a few ounces, for melting precious metals and for laboratory work, to 15 tons of steel, in large production units. The bath is normally cylindrical and is lined with acid or basic refractories, although basic linings are not entirely reliable, especially in the larger furnaces. Most furnaces, therefore, make use of a silica lining. This lining is formed with a dry cement which includes a bond, and is sintered or fritted in position by means of a hollow cylindrical former into which the first charge is placed. Normally this former is made of welded or cast steel, as it is essential to frit the lining at the maximum operating temperature. The lining is surrounded by a helical coil of flattened copper tubing which carries the current. It is normally protected with insulating varnish and asbestos tape.

In small furnaces, say up to 5 cwt. in capacity, the shell of the furnace is made of asbestos-cement boarding bolted on to a non-magnetic framework. The reason for this is that magnetic material such as steel would heat up due to the stray field outside the coil. For large furnaces, however, the only practical method of construction is a steel shell and, in this case, a magnetic shield consisting of packets of silicon steel laminations forms a yoke around the inductor coil. These packets of steel laminations also serve to support the coil. The furnaces are normally of the tilting type, and are frequently provided for nose-tilting by means of hydraulic rams or an electric winch and cable.

This type of furnace is commonly operated at a frequency above normal and very often a 500 cycles per second furnace is called a "medium-frequency" furnace, whereas that operated at a frequency exceeding 1,000 cycles per second is called a "high-frequency" furnace. Nearly all large industrial furnaces exceeding, say, 5 cwt. in capacity are energized by a motor-generator set. Small furnaces, however, for melting up to 20 lb., can be operated with mercury spark-gap converters which generate current at a frequency of 10,000 to 20,000 cycles per second. Thermionic valve-operated converters are also available with capacities of up to 50 kW., operating at a frequency of 200 to 1,000 cycles per second. Yet another type of mercury-arc high-frequency generator will produce a frequency of the order of 2,000 cycles per second.

The motor-generator type of plant predominates, and constitutes about 90 per cent of the melting capacity. This equipment consists of a driving motor, a high-frequency generator and an exciter, mounted on a common bedplate. A three-phase induction or synchronous motor is used, and this drives a single-phase homopolar inductor generator or a heteropolar machine. The power factor of this type of induction furnace is only .1 so that it is necessary to bring it up nearer to unity by connecting a bank of condensers in parallel with the inductor coil. The capacity required in the circuit depends upon the melting conditions, so that part of the bank of condensers has to be made variable. This type of furnace has largely replaced the crucible furnace for the manufacture of tool steels and highly alloyed steels, and it is preferred for nickel/chromium heat-resisting alloys, stainless steels, magnet steels, and—generally speaking—alloys which contain a preponderance of expensive elements, such as cobalt, tungsten, vanadium, chromium and nickel. It is also preferred for alloys which require a very low carbon content, as the metal is melted out of contact with carbon.

Recently, this type of furnace (Fig. 5.9) has been designed for operation from a mains-frequency supply of 50 cycles per second, but normally

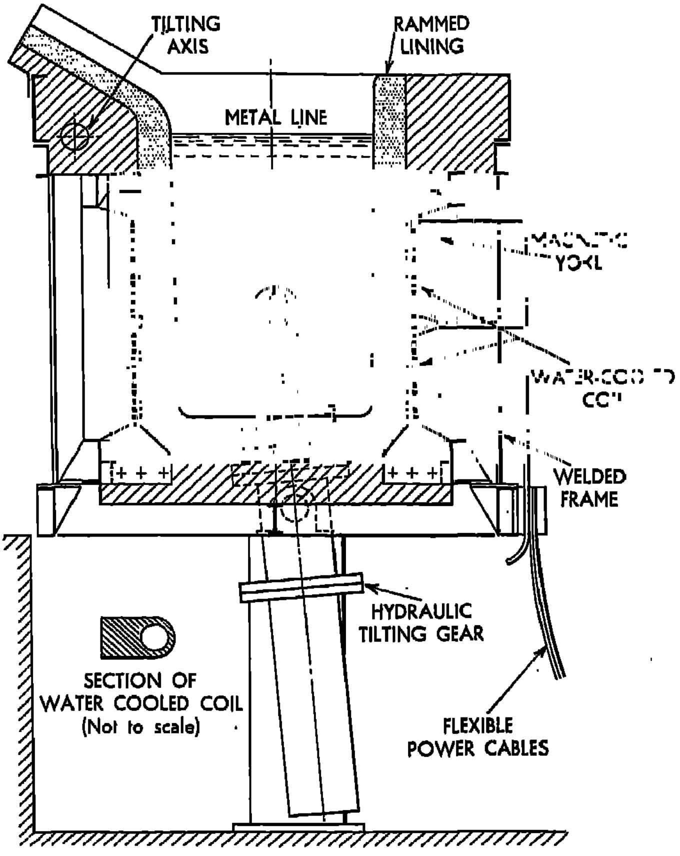


FIG. 5.9. *Cross-section of mains-frequency coreless induction furnace.*

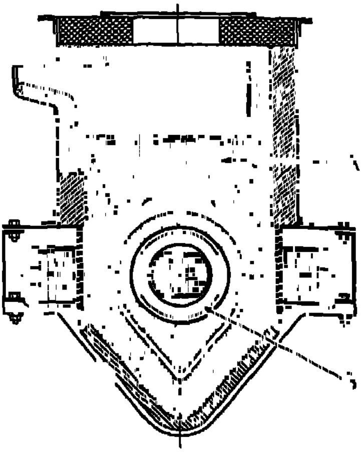


FIG. 5.10. *Low-frequency furnace of the Ajax-Wyatt type. (A) is the bath of molten metal. (B) is a coil wound on the centre leg of a laminated iron core; this induces the heating current in the V-shaped channel of molten metal.*

the mains-frequency, coreless induction furnace can only melt charges which consist of large lumps of metal averaging, say 6 to 8 in. diameter. For melting smaller material, it is essential to leave a pool or "heel" of molten metal so as to absorb the charge. Such furnaces are preferred for melting cast-iron borings in which the borings are fed into the molten pool of metal. This type of furnace has the advantage that it eliminates the motor-generator. For connexion to a three-phase supply the electrical equipment includes a phase balancer and capacitors, to improve the power factor. In all coreless induction furnaces there is a rapid circulation of metal which is ideal for alloying purposes as it produces complete homogeneity. However, the furnace is normally not suitable for refining by means of slags, which are relatively cold, not being heated by induced currents.

Channel-type Induction Furnaces. The first furnaces of this type consisted of an annulus, or ring of metal, which formed a single-turn secondary of a transformer. The bath of this furnace was inconveniently shaped, and the capacity was limited because of electrical considerations. It was found, however, that if the short-circuited loop of metal was submerged below a bath, thereby providing a hydrostatic head, many of the disadvantages were eliminated. The earliest furnace of this design is shown in Fig. 5.10. The secondary channel is in the form of a V, and the main bath of metal is superimposed above the V-slot. Most of the heat is generated in the V-slot, but there is a rapid circulation of metal caused by electrical and thermal effects which serve to heat the molten metal above. It is essential to keep the furnace at least one-third full of metal, the solid charge to be melted being added to the heel of molten metal. This type of furnace has been used widely for melting brass for ingot manufacture, and furnaces operating on the same principle are now used for aluminium, die-casting alloys, and cast iron.

The other types of furnace do not have the secondary channel in the form of a V; for instance, one type has two separate chambers, one for melting and one for holding the metal before casting, and these chambers are connected by two inclined channels. The primary coil and the iron yoke constituting the primary of the transformer are located between the channels. This type of furnace is often used for the die-casting of aluminium

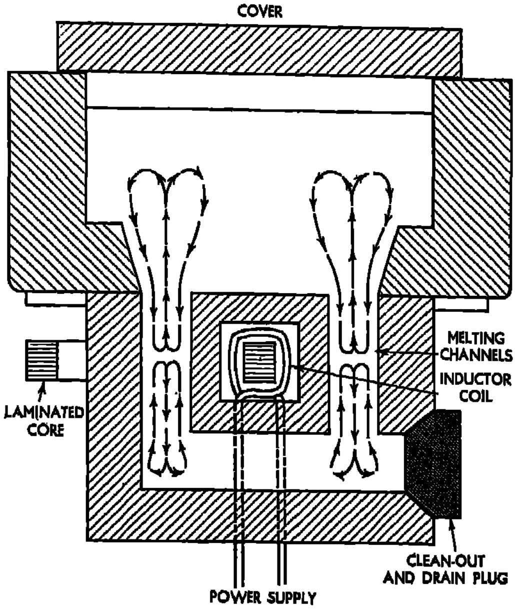


FIG. 5.11. *Diagrammatic section of a single-coil, low-frequency Tama furnace, showing the inherent stirring action.*

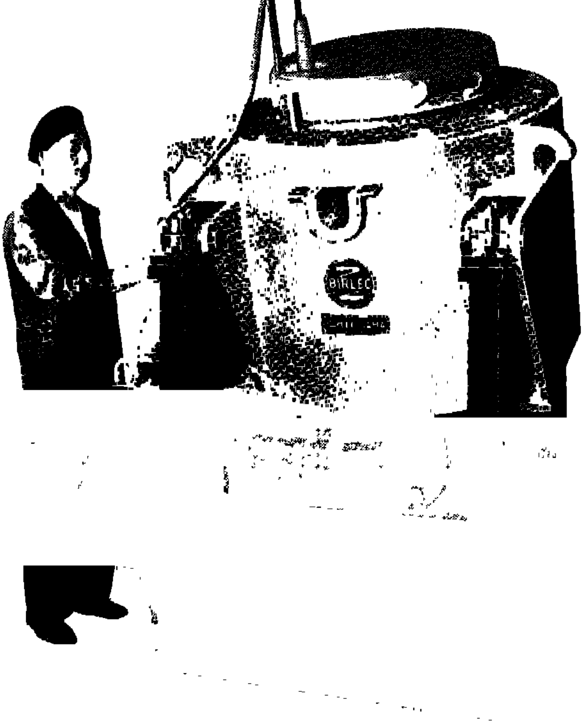


FIG. 5.12. *A 45 kW, low-frequency furnace of the type shown in Fig. 5.11, employing hoist tilting.*

alloys and brass. The cold metal is charged into one chamber while the other chamber serves as a holding bath from which metal is ladled or siphoned. The dross accumulates in the melting or charging chamber from which it is skimmed. These furnaces are made in sizes ranging from 20 to 100 kW. with melting capacities up to 500 lb. per hour.

Another type of furnace with a submerged channel has been developed particularly for aluminium and zinc alloys; it is shown diagrammatically in Fig. 5.11. The submerged channel is rectangular and the horizontal leg is of greater cross-section than the two vertical legs, so that any dross which may accumulate is deposited in it and can be cleaned out. Fig. 5.12 is a general view of this furnace, which can also be used for brass and other copper alloys.

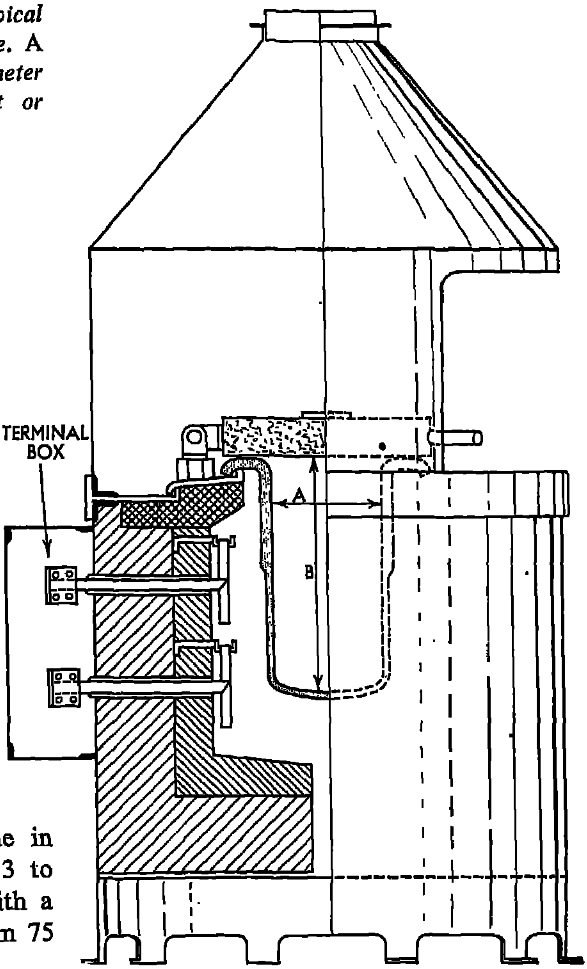
Many of these channel-type furnaces are built with two channels and the primary winding is Scott-connected to form a balanced three-phase load from a normal supply. Most of these induction furnaces are made suitable for connexion to a normal 400 to 440 volts supply, and are provided with an auto-transformer to give voltage, and therefore load variation. The primary coil is often cooled by means of a fan. .

RESISTOR FURNACES

There are two main classes of resistor furnace. The first type is heated by resistance alloys such as 80 : 20 nickel-chromium tape or rod, and generally comprises a crucible furnace for melting low-temperature metals such as solders, type metals, bearing metals and sometimes aluminium. The pot, or crucible, is made either of cast iron or heat-resisting alloy, but occasionally a graphite or plumbago crucible may be used. The heating elements are disposed around the outside of the pot, or container, for the molten metal, and the furnace is housed in a steel shell filled with heat-insulating and refractory material. The heating elements are normally supported on the refractory lining. Fig. 5.13 shows a furnace of this type.

The second type of resistor furnace is suitable for higher temperatures and resembles the indirect rocking arc furnace. Instead, however, of an arc which is struck in the centre of the furnace, the heating source is a horizontal, graphite resistor rod, as shown in Fig. 5.14. The furnace is invariably cylindrical and lined with a suitable refractory, a graphite resistor rod being mounted horizontally and parallel with the cylindrical shell. It is rocked on a horizontal axis to distribute the radiated heat and to enable the refractory to be washed by the molten metal. The resistor rod is mounted in graphite resistor-holders and is on a carriage which enables the resistor to be removed from the furnace casing for charging. This type of furnace has been used for melting and superheating special cast irons, and is also suitable for melting bronze and other copper alloys.

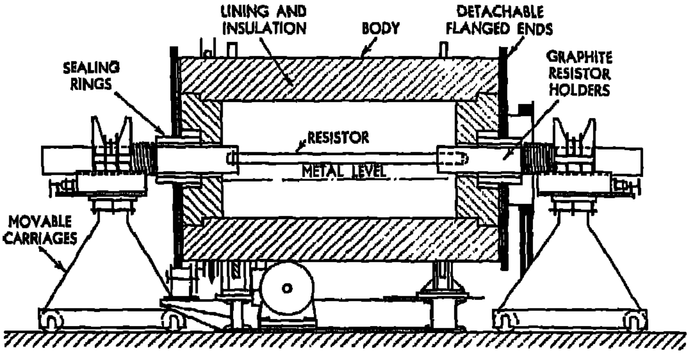
FIG. 5.13. *Section of typical crucible resistor furnace.* A *and* B *indicate the diameter and depth of the pot or crucible.*



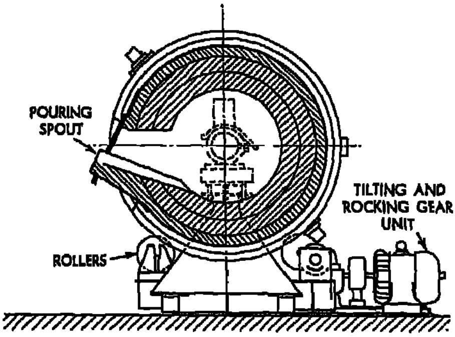
It is generally made in sizes ranging from 3 to 20 cwt. capacity, with a power input of from 75 to 350 kVA.

ROTARY FURNACES

A rotary furnace consists of a cylindrical steel shell, lined with refractory material, which can be rotated or oscillated slowly about its main axis. The furnace is usually tapered at both ends, the burner being at one end and an exhaust system at the other for waste gases, often in conjunction with a recuperative system for preheating the combustion air. The fuel may be oil, gas, or pulverized fuel, and the air is supplied by a fan or blower. On small furnaces, rotation may be by hand, but most of these furnaces are mounted on rollers and driven by means of a chain or friction drive. The high-temperature flame melts and superheats



LONGITUDINAL CROSS SECTION



CROSS SECTION

FIG. 5.14. *Rocking resistor furnace heated by the passage of electric current through the horizontal resistor rod.*

the charge, while the refractory lining is raised to a high temperature, and on rotation heat is transferred to the underside of the metal charge. This reduces melting time and helps to overcome the heat-insulating effect of slag. Melting conditions may be neutral, oxidizing or reducing in nature.

The capacity of rotary furnaces varies widely. For brasses and bronzes, capacities are from 1 cwt. to about 5 tons, usually in the range of 1 to 40 cwt. For melting cast iron, and sometimes steel, capacities can be much higher. (The new German "Rotor" installed at Oberhausen is a 60-ton unit, with 100-ton plants planned, but these are specialized furnaces for steelmaking and not intended for routine foundry work.) Metal may be tapped from a single opening in the cylinder wall which is kept closed with refractory during rotation. Larger units have an inching control to give a smooth flow during tapping. In some installations the furnace may be tilted backwards or forward to facilitate charging, pouring and slagging. These are called "end-tilting" and "lip-axis" rotary furnaces.

A modern installation for the larger type of rotary furnace is shown in Fig. 5.15. The ends of the body (*A*) are of conical form and spring-loaded to allow for expansion of the lining. The shell is fitted with two machined tyres (*B* and *B*) which are carried on two pairs of rollers driven through suitable reduction-gearing from an electric motor. The furnace is automatically rotated, and operation is controlled by push-button, which allows one operator to supervise more than one furnace. The burner fires directly into the furnace through one of the conical ends, the products of combustion being evacuated at the other end, which also serves as a charging hole. A retractable end flue (*C*) can be wheeled into position as soon as the charging of the furnace is completed, and serves to evacuate the products of combustion, either to a stack or to a suitable metallic preheater (*A*) in which the air supply for the burner can be preheated to 200 to 500 deg. C. A recuperator is usually incorporated in the layout when the furnace is required for dealing with steel, cast iron and the higher melting-point, non-ferrous metals. The recuperator unit may be either at ground level or of the totally enclosed, below-ground type with its accompanying flue system.

The rotary furnace is suitable for a great variety of foundry work, including grey, high-duty and malleable irons and steels at one end of the scale, and copper, gunmetal, bronzes, aluminium and lead at the other. Oil fuel is generally used for the higher melting temperatures, while oil, gas

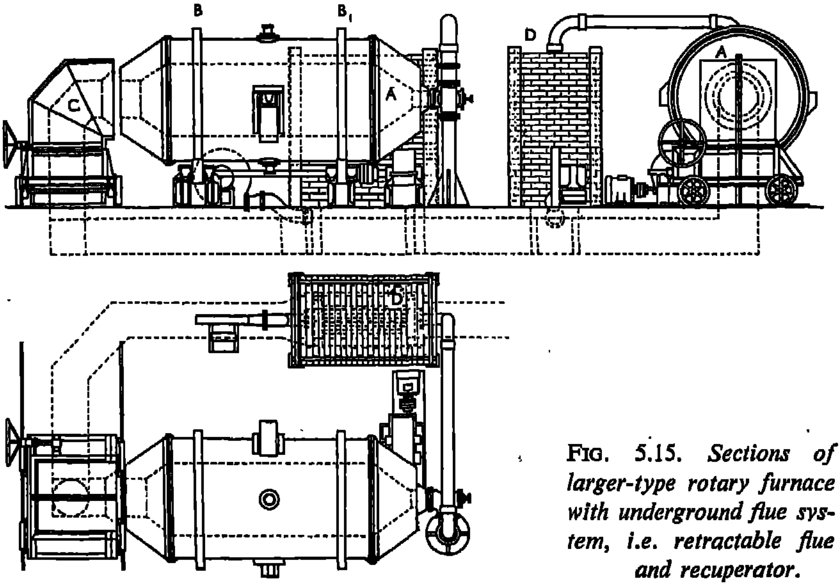


FIG. 5.15. *Sections of larger-type rotary furnace with underground flue system, i.e. retractable flue and recuperator.*

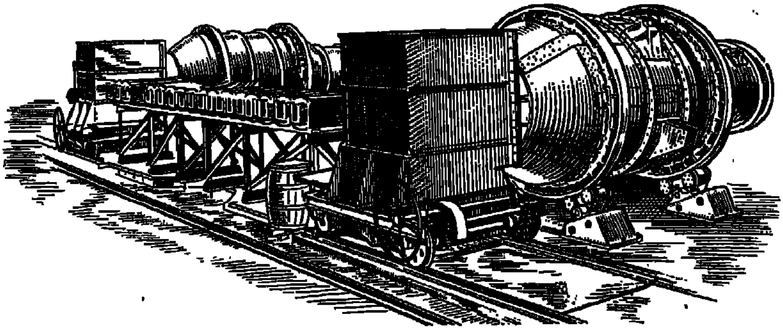
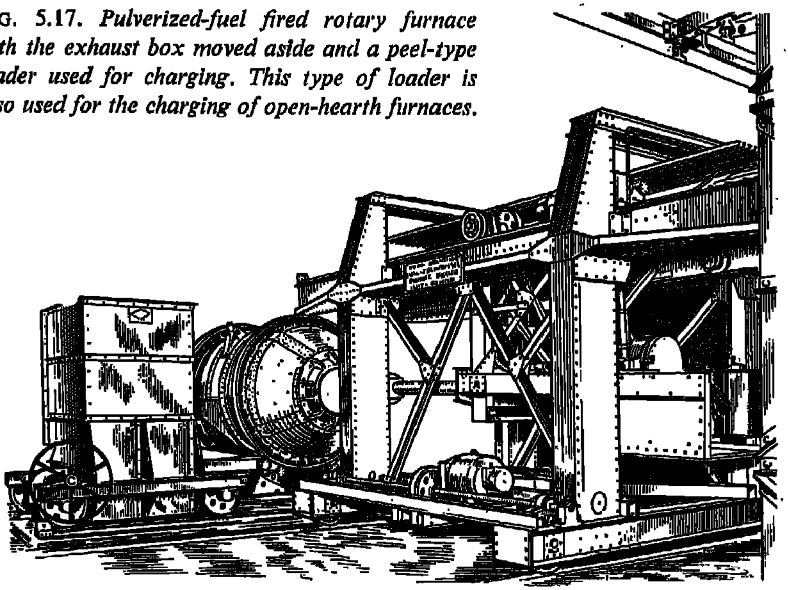


FIG. 5.16. *Two pulverized-fuel fired rotary furnaces, showing the movable exhaust boxes. The exhaust gases are taken through these exhaust boxes and used for preheating the blast. Charging is carried out at the exhaust-box end.*

or pulverized fuel are capable of giving equally satisfactory results for the medium and lower range, the choice largely depending on prices and availability. The lining of the rotary furnace may be either of rammed refractory material or of high-grade firebricks, the choice depending on the class of work for which the furnaces are required.

Semi-rotary melting furnaces are available with capacities of up to 3 tons for the melting of copper, gunmetal, bronzes, brasses and aluminium.

FIG. 5.17. *Pulverized-fuel fired rotary furnace with the exhaust box moved aside and a peel-type loader used for charging. This type of loader is also used for the charging of open-hearth furnaces.*



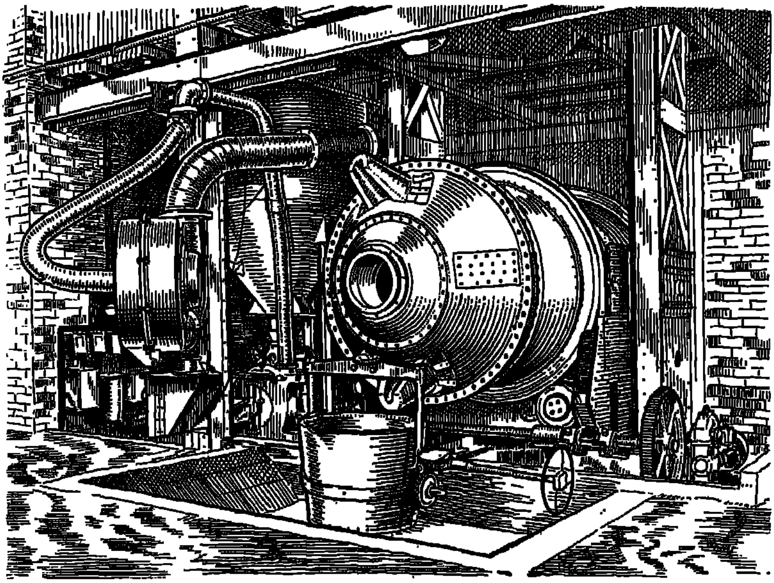


FIG. 5.18. *Tilting-type pulverized-fuel fired rotary furnace. The furnace tilts about its central axis and the burner is shown swung aside for tapping. The angle of tilt can be controlled to allow small quantities of metal to be taken if required.*

At intervals during melting, the furnaces are rolled over from one side to the other, as distinct from complete rotation. Temperatures can be taken up to 1,350 deg. C. An advantage is that the space occupied by the furnace is quite small. Examples of rotary furnaces are shown in Figs. 5.16—5.18.

REVERBERATORY FURNACES

A reverberatory furnace is essentially one in which fuel is burned at one end of a furnace chamber, so that the flame and products of combustion are deflected downwards by the shape of the roof on to the charge on the hearth, which lies in their path, then toward the exit flue and the stack at the opposite end. The heat from the roof is also radiated downwards on to the charge. Typical examples are the puddling furnace for wrought-iron production, and the air furnaces used largely in the manufacture of malleable iron and for melting non-ferrous metals.

Air Furnaces. In the air furnace, the charge is melted in a fairly shallow-walled hearth by the flame from fuel in a burner or firebox at one end of the hearth. Early furnaces were only designed to melt about 8 to 10 cwt. of metal, but in modern types their capacity is between 10 and

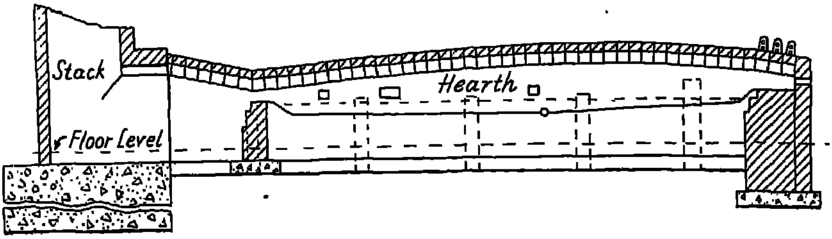


FIG. 5.19. *Sectional view of typical air furnace.*

30 tons, and with some 75 to 80 tons. A typical air furnace is shown in Fig. 5.19. It is particularly suited to the manufacture of blackheart malleable castings, for producing metal for cast-iron rolls and for large bronze castings, e.g., marine propellers, as the slow melting and batch system permit close control of the melting operation.

In such a furnace for malleable iron, the walls are usually of neutral firebrick enclosed in cast-iron or steel plates, with a fritted silica sand or firebrick bottom. The inside width is usually between 5 and 10 ft., the length being anything from 15 to 50 ft. The roof consists of a series of firebrick arches, which are normally removable in larger units to facilitate charging and maintenance. The roof is arranged to slope downwards from the firing end toward the chimney end. The height of roof above the hearth is determined by the space required for the unmelted charge, say 18 to 22 cu. ft. per ton of charge.

If the furnace is fired by lump coal, a fire-grate is provided, separated from the hearth by a bridge about 1 ft. 6 in. to 3 ft. high. The hearth slopes toward the taphole, usually situated between the furnace centre and firing end. Large furnaces are usually fired with pulverized coal or with oil. The average depth of the bath is important; a large hearth and shallow bath give a rapid superheating of the molten metal at the expense of oxidation losses. The design, therefore, aims at an economic balance.

The usual charging practice is to put light scrap on the hearth, followed by larger malleable and steel scrap, including rolls, and finally any pig iron is placed on top. In this way the smaller material is near the bottom and the larger helps to protect it from excessive oxidation. This method also ensures that the materials with the lowest melting points are at the top. Charging is normally carried out through the roof, although some furnaces are charged by hand through the doors, which are also used for rabbling and sampling. The doors should be as airtight as possible so as to maintain the maximum draught from the chimney.

A 30-ton heat can be melted at a faster rate per ton than a 15-ton heat, although the total time for one operational cycle is longer. This often leads to the installation of smaller units to provide more heats per day. In an efficient furnace, a 25-ton charge can be melted in about six hours. Sometimes exit gases are recuperated, so as to preheat incoming air. Once tapping has begun, it is advisable to remove all the metal from the furnace as quickly as possible to avoid oxidation losses as the remaining metal becomes shallower. The loss of carbon in melting cast iron is usually about 15 per cent of the carbon charged. The loss of silicon and manganese is a little higher, about 20 per cent. The air furnace may be used in conjunction with a cupola for duplexing.

Small reverberatory furnaces from 1 cwt. to 2 tons, often oil-fired, are sometimes used for non-ferrous metals, for example, brasses and bronzes. They can be stationary or tilting. One of the new smaller units is the "dry hearth" reverberatory furnace. In this, metal of the lower melting-point category (for example, aluminium) may be melted on a steeply sloping hearth. As the metal melts it quickly runs into an adjoining well-insulated, open-top, holding chamber from which it is ladled for use. This avoids over-heating the molten metal and prevents the formation of oxide on the hearth. Firing is by gas, oil or a combination of both, directly on to the charge. Melting capacities vary from 300 to 2,000 lb. of aluminium per hour, with corresponding bath capacities of 500 to 2,000 lb.

Open-hearth Furnaces. These furnaces, often known as Siemens or Siemens-Martin furnaces, are widely used for the melting and refining of steel for ingot manufacture, and are the principal method of steelmaking in Britain and in the U.S.A. They range from 25 tons to 500 tons in capacity. Some years ago small open-hearth furnaces, generally from 15 to 30 tons in capacity, were used in the larger steel foundries but they are mostly being replaced by electric furnaces. There are, however, a few furnaces still operating for the manufacture of large castings, weighing 50 tons and upwards, and for that reason a short description of this type of furnace is given.

The open-hearth furnace is fired with oil, coke-oven gas, producer gas, or mixed blast-furnace and coke-oven gas if this is available. If a low calorific gas is used, such as producer gas or mixed gas, then it is essential to preheat the gas in a regenerator. The air is always preheated in a regenerator to give maximum thermal economy and to enable a high flame temperature to be obtained.

The furnace is a rectangular refractory enclosure with fuel and gas ports at each end, as shown in Fig. 5.20. These ports are of varying design but all of them are intended to direct the gases downwards on to the charge or bath of metal. The flame and hot gases traverse the bath and then pass out at the opposite end of the furnace. The waste gases pass through

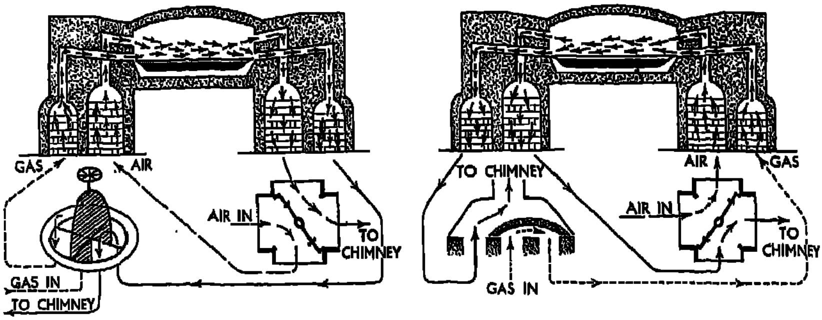


FIG. 5.20: *Open-hearth furnace installation.*

one or two regenerators on their way to the stack; frequently, waste heat boilers are placed after the recuperators in order to recover further the heat in the products of combustion. Periodically, the fuel and airflow are reversed by means of water-cooled valves, and the furnace is then fired from the opposite end. If a high calorific-value fuel, such as oil or creosote pitch, or even coke-oven gas, is used, then the fuel is not regenerated and there is only one air regenerator at each end of the furnace.

In recent years oxygen has been used in open-hearth furnaces to increase the flame temperature during the initial stages of melting. An oxygen jet, or lance, is also used to assist in carbon removal during the refining of pig iron into steel.

Open-hearth furnaces can be of the fixed or tilting type, the tilting type being preferred mainly for the refining of high-phosphorus pig irons. In the manufacture of ordinary quality steels, the basic-lined furnaces are generally used, but the acid-lined, open-hearth furnace is still used in Sheffield in the manufacture of high-quality steels using selected raw materials.

CONVERTER PLANTS

All converter plants are based upon Bessemer's original invention of blowing air through molten iron to oxidize the impurities, such as carbon, silicon and manganese, thereby deriving sufficient heat of oxidation for the conversion of the pig iron into steel. The Bessemer process is used widely in large steelworks for the conversion of liquid pig iron from a blast-furnace plant into steel for ingot manufacture. For pig irons containing phosphorus, a basic lining is used, this process often being referred to as the "Thomas process." Where sulphur and phosphorus content is extremely low (below 0·04 per cent) an acid Bessemer converter is used. These converters vary in size from 10 to 60 tons for ingot steel manufacture,

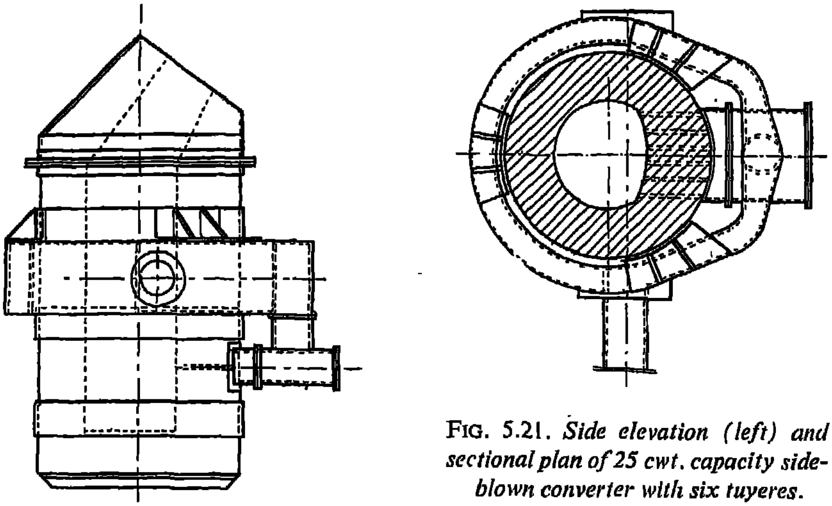


FIG. 5.21. *Side elevation (left) and sectional plan of 25 cwt. capacity side-blown converter with six tuyeres.*

all being bottom blown. However, Bessemer converters are rarely used for the production of castings.

Several conversion processes have been developed recently which dispense with the use of air, the carbon and other elements being oxidized by means of pure oxygen or an oxygen-steam mixture. The oxygen is top blown through a high-pressure jet, or it may be injected by other means. Most of these processes, however, are used for large-scale ingot manufacture, and have not yet been applied in the steel foundry. The main conversion process in the steel foundry uses a so-called side-blown converter, often called the "Tropenas converter." The metal is generally melted in a cupola and can consist of iron and steel scrap and also pig iron. It is, however, essential to have sufficient silicon, manganese and carbon in the cupola metal to ensure that there is enough heat of oxidation in these elements to raise the temperature of the cupola metal to that of liquid steel, namely from about 1,300 to 1,600 deg. C. If, therefore, the carbon content is low, then the silicon content must be increased by ferro-silicon additions, but occasionally the manganese content is increased.

The side-blown converter is essentially an acid steel-making process so that the sulphur and phosphorus are not removed, and the content of these elements in the cupola metal must be lower than that required in the finished steel, unless other special methods are used to remove these impurities.

Within recent years, oxygen-enriched air containing up to 35 per cent oxygen has been used for side-blown converters, and in these cases much lower silicon, carbon and manganese contents can be used. This is because

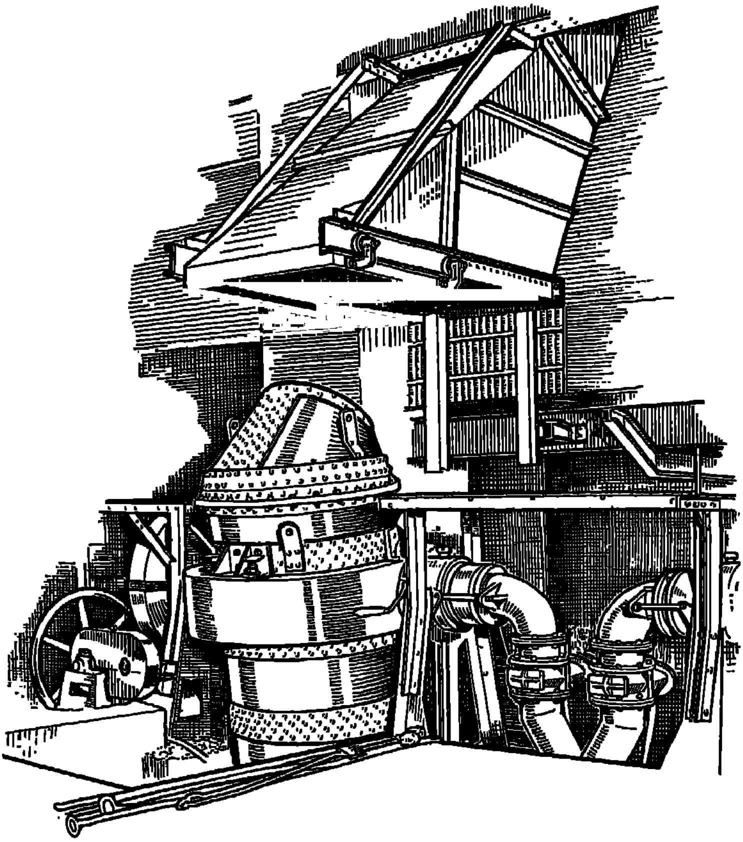
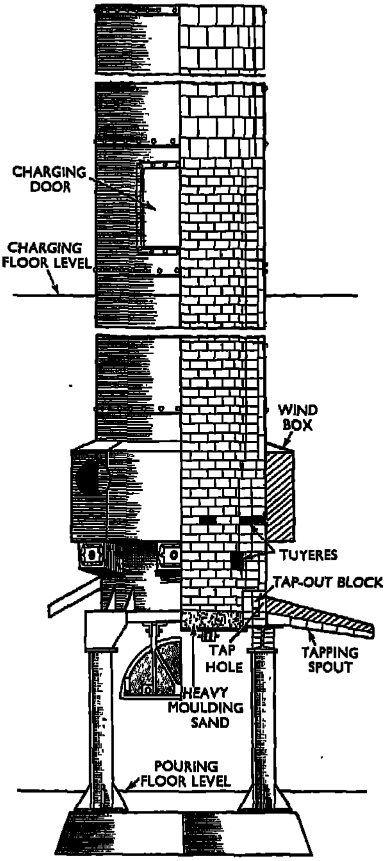


FIG. 5.22. *Tropenas side-blown converter installation for producing steel from molten cast iron. The air blast is supplied by a fan or blower at a pressure of 3-5 lb./sq. in. The hood above enables fumes to be carried outside the building.*

much of the nitrogen is eliminated and does not have to be heated to converter temperatures. Side-blown converters are built in sizes ranging from 15 cwt. in capacity up to 7 tons. A section of a typical side-blown converter is illustrated in Fig. 5.21, and in Fig. 5.22 a works installation is shown. It will be seen that the vessel is approximately cylindrical, whereas the internal lining is nearly D-shaped in cross-section. At the top of the vessel there is a truncated conical hood to allow the converter fume and gas to escape.

The converter is mounted in trunnions for tilting and at the level of the trunnions there is a wind-belt which leads to the tuyeres at one side of the vessel. Normally, five or seven tuyeres are used and when the converter

FIG. 5.23. *Sectional view of a modern drop-bottom cupola.*



is in the blowing position the air is blown just on to the surface of the metal. The air pressure should be 3 to 5 lb. per sq. in. and is normally delivered by a positive-displacement blower or a two-stage fan. The depth of metal is generally 12 to 15 in. and the area of bath approximately 5 sq. ft. per ton of capacity.

Normally the blowing time is 15 to 20 minutes, but this can be reduced with the use of oxygen and the converter plant is normally designed to produce between two and three heats of steel per hour. It is a rapid steel-making process which gives a succession of heats and for that reason is often preferred for a small foundry.

CUPOLAS

The cupola furnace is used almost exclusively for the production of cast iron, although small furnaces of this type are employed for the melting of copper where large quantities of this metal are required. It is not suited for the melting of brass and bronze because of the excessive oxidation of zinc and tin which occurs, but they are sometimes made by cupola-melting the copper and adding the necessary alloys to the molten metal.

The cupola consists of a steel shell mounted in an upright position on a base plate which is usually supported on four steel joists or tubular columns. Most modern furnaces are of the drop-bottom type, that is, hinged doors are provided in the centre of the base plate which can be lowered to allow the debris from the furnace to be discharged at the end of a run. Originally, cupolas were built on a brick foundation, in the place of columns, and furnaces of this type are still in use today and are known as

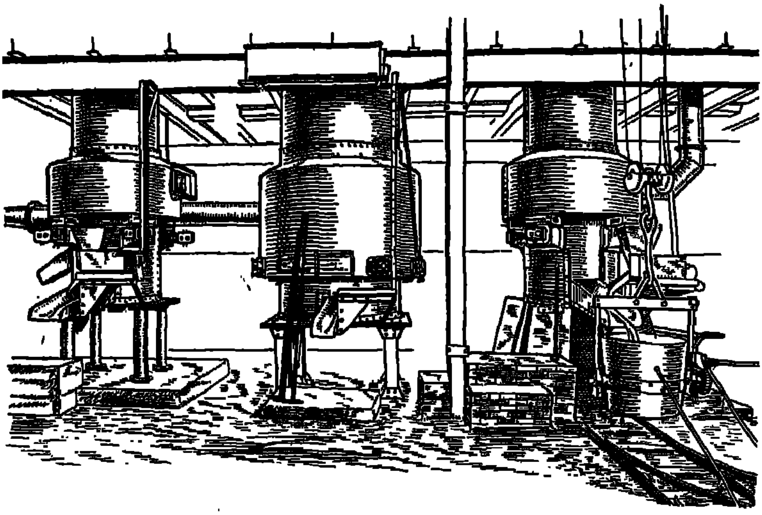


FIG. 5.24. *Cupola installation in an iron foundry, consisting of three furnaces of different sizes. Each cupola is supported on columns so that the debris remaining at the end of a melt may be discharged when the bottom doors are dropped.*

solid-bottom cupolas. A modern drop-bottom cupola is shown in Fig. 5.23, and an installation of three cupolas is shown in Fig. 5.24.

The steel shell is usually of $\frac{1}{4}$-in. plate of riveted or welded construction. Thicker plate, up to $\frac{1}{2}$ in., is used on very large sizes. There is a wind-belt or blast box 2 to 3 ft. above the base plate. This is usually 2 to 5 ft. deep and surrounds the shell. The air is supplied to the wind-belt from a fan or Roots blower, and the blast is conveyed to the interior of the furnace by tuyeres, which may be situated in or under the wind-belt. The number of tuyeres used depends on the size of the furnace, and it is usual to allow one tuyere for each 6 in. of internal diameter. The height at which the tuyeres are set above the working bottom of the furnace depends on the holding capacity for molten metal required. For example, if the metal is to be continuously drawn from the cupola as it is melted, the tuyeres may be set only 12 in. above the working bottom. If the maximum holding capacity for molten metal is required, a height of 3 to 4 ft. from the working bottom to the tuyeres may be allowed. It is unwise to exceed this latter height as tuyeres placed too high result in cold metal being produced in the early stages of a melt.

The working bottom in a drop-bottom cupola is made up with moulding sand through a fettling hole provided at the bottom of the shell. This fettling hole is used on solid-bottom cupolas for raking out the debris at the end of a melt. The fettling hole is usually about 18 in. square and is covered by a plate held in position by a bar during the operation of the furnace. A metal tap hole is provided at the front of the furnace and the working bottom is made to slope toward this. The average thickness of sand used in the bottom of cupolas up to 5 tons per hour capacity is 5 to 6 in., and this may be increased to 12 in. on very large cupolas. A slag hole is provided about 8 or 9 in. below the centres of the tuyeres. This should be located midway between two tuyeres, as otherwise the cold air blast may chill the slag and prevent it running freely from the slag hole. A charging hole is provided at a height of 12 to 15 ft. above the tuyeres, depending on the size of the furnace. On very large cupolas this height may have to be increased to 20 ft.

Tuyeres. Tuyeres are the nozzles through which air under pressure is forced into the furnace from the wind belt via a pipe from the blowing equipment. Much has been written and said regarding the size and shape of tuyeres for cupolas. The present tendency is to return to the most simple form of tuyere and to use a single row of round or rectangular tuyeres which are parallel throughout their length. The area of tuyeres generally found to give the best results in practice is one-fifth to one-seventh of the cross-sectional area of the furnace at tuyere level. If round tuyeres are used these should be not more than 5-in. diameter on cupolas up to 36-in. inside diameter, and not more than 6-in. diameter on larger cupolas. Rectangular tuyeres are usually 4 to 5 in. deep, with a width about one and a half times their depth.

The normal output, or the rate at which a cupola will melt, is controlled very largely by the internal lined diameter at tuyere level. The output from a cupola under normal operating conditions is approximately 0·75 ton per hour per sq. ft. of area at this level. Output up to 1 ton per sq. ft. can be obtained under favourable conditions, such as when light, easily melted scrap is used with a minimum of coke. The output from a cupola is influenced by the amount of coke used, and where the ratio of metal to coke is low the output will also be low. In other words, the question is more one of burning coke than of melting metal. In designing a furnace, in normal circumstances, to yield a certain rate of melting it is usual to assume that an output of about 0·75 ton per sq. ft. of bore area will be obtained. It should be remembered that the output is always low for the first hour of a melt, while the furnace is becoming thoroughly heated. On long melts, due to lining erosion, higher outputs may be obtained during the later stages of the melt.

CUPOLA LININGS

The cupola lining may be of firebrick, or it may be rammed up. Such linings are known as monolithic or rammed linings and, if the ramming and drying are carefully carried out, they will give as long a life as the best-quality firebrick lining. The thickness of lining depends on the size of the furnace and the length of the heats required. For a normal furnace operating, say, 4 to 6 hours per day with an output of 5 tons per hour, a lining of 9-in. thickness is used. It is unusual to have a lining more than 12 in. thick even on large cupolas, unless the conditions of operation are very severe. The thickness of the brick-work in the chimney above the charging hole is usually only 3 or 4½ in. Many cupolas are lined parallel from baseplate to charging hole. Where the cupola is relatively short from tuyeres to charging hole, the lining can be flared out to give a greater area above the tuyeres. This increases the holding capacity of the preheating zone above the top of the coke bed, and may considerably increase the economy of working. The diameter of the flared-out portion is usually 6 to 9 in. greater than that in the tuyere zone, and the flare should begin 2 to 3 ft. above the tuyeres and be about 2 ft. deep. A flared lining is *not* advisable in the following cases:

(1) Where a number of different mixtures are melted in one heat, if a maximum separation of these mixtures is required without emptying the cupola after each.

(2) Where the height from tuyeres to charging hole is greater than normal and ample preheating space for the charges is available with a parallel lining.

(3) Where the cupola is to be emptied more than once during a heat to separate different mixtures. A flared lining will then increase the time required to empty the furnace and thus the wear on the lining will be increased.

In order to obtain the maximum efficiency from a cupola the volume of preheating space provided should be sufficient to accommodate the metal, coke and limestone required for approximately one hour's melting.

CUPOLA OPERATION

In the correct operation of a cupola, a fire is first lit on the working bottom and coke is added in small quantities until it reaches the level of the tuyeres. The fire is then drawn up by natural draught until this coke is thoroughly heated, the air being drawn in through the open fettling hole and slag hole. Kindling tuyeres, or a small auxiliary blower, are sometimes used for burning up the bed coke rapidly. When the coke is well alight the fettling hole is closed with sand and covered with a steel plate. More coke is added to bring the bed to its final level and the height should be checked by a measuring stick inserted at the charging hole. Care should be taken to see that the coke is well alight and burning freely, especially at the tuyeres, before any charges are put on.

When the condition of the bed is satisfactory, charges should be put on to fill the furnace to the level of the charging hole. Alternate charges of metal and coke are used, the flux charge, usually limestone, being charged with the coke. When the cupola is full the air blast may be put on and in 5 to 7 minutes molten metal should be seen passing the tuyeres. Some cupola operators prefer to leave the metal tap hole open until metal is melting freely and running hot from the furnace. It is then closed with a clay bot. Others close the hole, after thoroughly drying it out, before the blast is put on. Metal is then allowed to collect in the well until sufficient has accumulated for a tap to be taken. This is judged by previous experience of the furnace. In the meantime alternate metal and coke charges should have been added to replace the metal melted, and this continues until the end of the melt. Slag is tapped from the slag hole at intervals of 45 to 60 minutes, or whenever it is considered that too great an accumulation of slag is building up in the furnace.

Where a cupola is used in conjunction with a receiver, continuous tapping is usually adopted. Metal and slag flow together through the tap-hole into a siphon box or tapping box. Here the iron and slag separate because of their different densities. The slag is led away above the metal level from the side of the box. The iron continues under a slag dam, over a weir and into the iron runner. The purpose of the weir is to keep sufficient molten iron in the siphon box to overcome the fluid pressure created by the slag, the cupola charge, and the blast pressure. The distance from the top of the cupola tap-hole to the top of the weir must be adjusted to the individual circumstances of slag height and blast pressure.

At the end of the melt, charging is stopped and the blast is maintained until inspection at the tuyeres shows that all the metal is melted. The blast should then be shut off immediately. In a drop-bottom cupola the bottom is then dropped and the debris remaining in the furnace is discharged. In cupolas with a solid bottom the fettling hole plate must be removed and the debris raked from the furnace. The debris is then quenched with water. The remaining coke, which should be approximately half of that originally required to form the bed, may be recovered and used on the charges of a subsequent melt. Before the cupola can be used again repairs to the lining must be carried out. The amount of repair work necessary depends on the length of the melt. Where operating conditions are severe it may be necessary to put in new firebricks in the melting zone where the maximum lining erosion takes place. As a rule, however, the repairs are carried out by patching with ganister to bring the lining back to its original dimensions. It is important that repairs are carefully carried out and the lining dried before the cupola is used again. For this reason it is an advantage to install two cupolas so that the lining of one can be repaired while the other is working. Where cupolas are operated on very long heats, the provision of a third cupola enables major repairs, such as relining, to be carried out without interruption to production.

The height that the coke bed is built above the tuyeres before the cupola is charged depends partly on the design of the furnace and partly on the conditions of operation. The most suitable height for the coke bed for any particular set of conditions is best determined by experiment. For melting highly phosphoric iron, when a very high tapping temperature is not required, a coke bed 2 ft. above the tuyeres may be adequate. On the other hand, if highly superheated metal is required as, for example, in the production of malleable castings, a bed height of 4 ft. 6 in. or more above the tuyeres may be necessary. With mixtures containing high proportions of steel scrap, it is usually necessary to employ a higher bed than when melting mixtures of pig-iron and cast-iron scrap. An average bed height for the melting of mixtures for general engineering castings is 2 ft. 6 in. to 3 ft. above the tuyeres.

Air Supply. Air is supplied to a cupola either by a positive blower of the Roots type or a high-pressure fan. The modern type of direct-coupled fan gives very satisfactory results and is largely replacing the positive blower because of its lower first cost, and also because there is less noise and vibration in operation, and less wear on moving parts. An advantage of the positive blower is that if the speed and displacement are known the volume of air passing into the cupola can be easily calculated. With a fan, some type of volume gauge is necessary if a knowledge of the amount of air passing is required. The amount of air required by a cupola can best be ascertained from the metal-to-charge coke ratio and the rate of melting required. From these two factors the weight of coke to be burnt per minute can be ascertained and the amount of air required to burn coke to carbon dioxide is approximately 135 cub. ft. per lb. of coke, assuming the coke contains 90 per cent carbon. It is unusual in cupola operation to obtain complete combustion of the coke to carbon dioxide, and thus the air required will probably be less than 135 cub. ft. In practice, however, because of air losses from leaks in the blast pipe and wind belt, more air is allowed than theoretically necessary, usually 150 to 160 cub. ft. of air blown per lb. of coke charged.

It is difficult to give any reliable guide to the pressure at which air should be supplied to cupolas, as much depends on the size of the tuyeres, shape of the lining and the character of the material charged. In normal operations the following pressure ranges are recommended:

Cupolas—bore	24 to 30 in.	30 to 40 in.	40 to 50 in.	50 to 60 in.
Water gauge	12 to 16 in.	16 to 22 in.	22 to 27 in.	27 to 35 in.

Metal and Coke Ratio. The ratio of metal melted to coke consumed is usually taken as an indication of the efficiency of cupola operation. It is sometimes assumed, for example, that if one cupola is melting 15 lb. of metal to each 1 lb. of coke used on the charges, the furnace is being operated more efficiently than another melting only 10 lb. of metal for 1 lb. of coke. This can, however, be entirely misleading, as many factors can influence this ratio, including the type of metal to be melted, whether easily fusible or not, the average size of the individual pieces charged, the temperature of molten metal required, the duration of the melt, the rate of melting required, and the quality of the coke used. It is obvious that the higher the temperature required, within limits, the higher will be the consumption of coke, and the melting of very heavy lumps also requires rather more coke than the melting of light scrap. If a low rate of melting is required from a furnace during certain periods, coke consumption must be increased if the temperature of the metal is to be maintained. When melting high percentages of steel scrap it must be remembered that some of the coke will be used in carburizing the steel itself. For the melting of mixtures containing 50 per cent steel a coke consumption between 6 : 1 and 8 : 1 should be considered good practice. In producing engineering castings from mixtures containing up to 25 per cent steel scrap, a ratio of 10 : 1 metal to charge coke is very satisfactory. For high-phosphoric iron for light castings ratios up to 15 : 1 can be obtained with good cupola practice. These rates apply to large cupolas. Slightly more coke is usually required by small cupolas for producing equivalent temperatures. Metal for malleable castings, whether containing steel or not, is rarely produced with a better metal-to-coke ratio than 8 : 1, on account of the very high temperature required.

Weight of Charges. There is, quite obviously, a weight of charge which will give the best results for each size of cupola, but this depends to some extent on operating conditions. In order to save labour the number of charges, and thus the number of weighings, is usually kept to a minimum by employing the heaviest charge that the cupola will melt successfully. The use of heavy charges also helps to give efficient combustion. The maximum weight of charge normally employed is approximately one-eighth to one-sixth of the hourly melting rate. Special considerations often make it advisable to use a much lighter charge than this, for example where the charges contain components of widely different composition, such as steel and pig iron, it is essential that the components of the charges mix properly, either in the well of the furnace or in the ladle. To ensure this a number of small charges is better than one heavy charge and, in such circumstances it may be better to use charges one-tenth or one-twelfth of the hourly output.

As stated previously, however, the weight of charge must depend on the size of the cupola and the operating conditions. This is quite apart from the consistency of the metal or alloy which is to be melted.

The ash that comes away from the cupola coke and the sand and rust adhering to scrap and pig iron must be fluxed away and, to accomplish this, an addition of limestone is made to the charges. In general practice the limestone addition should be 25 to 30 per cent of the weight of the coke charged. Such an addition will yield a slag containing approximately 25 per cent lime, which is clean running and not of a type likely to cause serious erosion of the lining. Very many foundries operate cupolas with an insufficient limestone addition.

Cupolas with Auxiliary Air Supply. As mentioned previously, it is unusual in normal cupola operation to burn coke charges completely to carbon dioxide, and a certain amount of carbon monoxide is produced which either burns at the charging hole or escapes from the top of the stack. This carbon monoxide represents a loss of heat, and special cupolas have been designed to reduce losses from this source. In the Poumay cupola small tuyeres deliver air at various heights above the top of the coke bed so as to complete the combustion of carbon monoxide produced at lower levels. The balanced-blast cupola has one row of special tuyeres, provided with air control valves, and two or more rows of adjustable auxiliary tuyeres in the wind belt. The amount of air admitted at the main tuyeres and auxiliary tuyeres can be adjusted so as to give the most efficient operation for any particular set of conditions. Where conditions are favourable both these cupolas have made a considerable saving in fuel compared to cupolas of conventional design.

RECENT CUPOLA DEVELOPMENTS

In recent years there have been several developments in cupola practice. They are not all new, but have come into use primarily because of increased labour and material costs. One such development is the increased use of water-cooled cupolas in which the melting zone is water-jacketed or the steel shell in this zone is water-sprayed. Water-cooling shows savings both in refractory and in maintenance costs. In this connexion water-cooled copper tuyeres are also often used. Water-cooling does remove heat from the melting zone but on large cupolas, say over 36 in. inside diameter, the savings make its adoption worthwhile. The other justification for water-cooling is where more than eight hours' operation is required. In special cases up to one week's operation or more has been obtained without dropping the bottom.

Hot-blast Cupolas. To economize in coke and to permit of a higher proportion of steel scrap being used in cupola charges, the adoption of hot blast has been increasing steadily. Hot blast enables poorer quality cokes to be used and also reduces the silicon loss in the cupola, while at the same time increasing carbon pick-up. The blast is generally heated to 400 to 500 deg. C., and three different systems of preheating are used:

(1) A specially fired air preheater which can be heated by oil, gas or other fuel. This is normally a tubular-type heat exchanger in which the fuel is burnt in a combustion chamber and the products pass over either the outside or inside of the tubes, the air blast passing over the other surface.

(2) The combustible content of the waste gases from the cupola and their sensible heat are utilized to heat the blast. Most of the top gases (say 75 per cent) are drawn through a combustion chamber and burnt with air, and the products of combustion pass through a metal recuperator to heat the blast.

(3) The gases are drawn off the cupola through an off-take just above the melting zone and only the sensible heat of these gases is used for preheating the blast by means of a recuperator.

There are several makes and types of hot-blast systems but that described under (2) is the one which is most widely used, and this will be described in greater detail. The top gas from a cupola normally emerges at a temperature between 350 and 500 deg. C. and usually contains from 12 to 16 per cent carbon monoxide. The sensible heat and its calorific value together amount to approximately 60 B.Th.U's per cu. ft. This gas is drawn off below the charging level by means of gas offtakes. It is common to narrow down the charging opening to form a constriction, so forcing the gas through the recuperative system. Usually, the hot gas passes through a dust catcher which may be in the form of a cyclone, and then passes, without much loss in temperature, through a combustion chamber which is located just ahead of the recuperator.

Two types of recuperator are in use. The first is the radiation type which consists of a heat-resisting steel cylinder with a diameter which may range from 2 to 3½ ft. and through which the hot gases pass and radiate on to the walls of the cylinder. The air is passed in contraflow around the outside of this cylinder, the air passage being formed by putting a cylinder of slightly larger diameter outside the inner, or "radiation receiving" cylinder. The space between the two cylinders, or what may be called the "annulus," is small to ensure fairly high air velocity, and this air can be given a spiral or vertical flow by means of guides. All the hot-gas ducting is lined with insulating bricks and the hot-blast main, which is normally made of steel, is insulated on the outside. On the top of the radiation recuperator, a chimney is normally mounted to increase the draught, and a

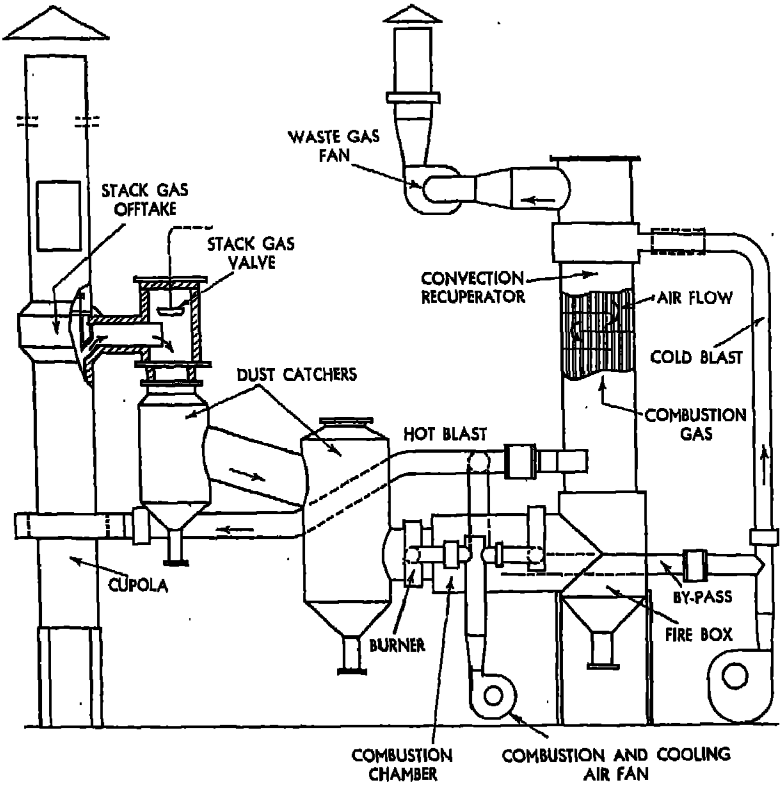


FIG. 5.25. *Diagrammatic arrangement of "M.E./Schack" convection recuperator in conjunction with a cupola.*

stack damper is installed to control this draught, thereby regulating the proportion of gas which passes through the recuperative system. Normally, the system is so controlled that about 75 per cent of the cupola top gas passes through the recuperative system, the balance passing out through the cupola charging opening and then to the stack so as to keep a pressure at the charging level and prevent air being drawn into the system.

The other type of recuperator which is commonly used is a convection recuperator (Fig. 5.25). This usually consists of a tubular heat-exchanger in which the products of combustion of the top gas either pass through the tubes, or over the outside of the tubes, the air passing over the other surface. The resistance in a convection recuperator is much higher than in a radiation recuperator, and an exhaust fan is generally provided to suck the gas through the combustion chamber and recuperator.

Whereas most of the heavy dust is removed in the dust catcher, the recuperator elements, of whichever type they are constructed, also accumulate dust. Means are provided for cleaning out the dust at intervals, as otherwise the efficiency of heat transfer is impaired.

Some cupolas do not have an open mouth for charging, but are provided with a closed top with a bell and hopper system. This can be done most conveniently on larger cupolas and in this case all the gas is passed through the recuperative system.

The advantages which hot blast offers for cupola operation are:

(1) A reduced coke consumption with the ability to use low-grade high-ash cokes.

(2) The ability to melt and carburize a higher proportion than normal of steel scrap for cast iron manufacture.

(3) A reduced silicon loss.

(4) The ability to produce higher casting temperatures, especially for light-section castings.

It should be emphasized that not all these advantages can be obtained at the same time; for instance, if the lowest coke consumption is required, then the proportion of steel scrap must be curtailed. With the increasing necessity of eliminating dust from industrial processes, the system of closing the top of the cupola, as described above, has many advantages as it is easy to install a dust-extraction system after the recuperator and before the waste gases are passed to the stack. With the open-charging method, dust can be removed by arranging a water spray on the top of the stack.

Another interesting development, although not yet widely used, is the introduction of the basic and the neutral lined cupola. The basic cupola was first lined with dolomite, but magnesite is now preferred. The use of a basic cupola enables a calcareous slag to be carried, thereby reducing the sulphur content and having the effect of increasing carbon pick-up. This is useful in the production of nodular graphite cast irons. The slags must be carefully controlled to achieve consistent results. A later development has been the use of carbon linings which can operate under either acid or basic slag conditions.

Recently there has been more use of mechanization in the charging of the cupolas and many small cupolas are now charged by means of skips or swing-frame charging machines which hoist a drop-bottom bucket up to the charging opening. The latter arrangement is preferred for large cupolas as it is easy to control the distribution.

Where small quantities of metal are required, small cupolas known as cupolettes are sometimes used. They have proved of value when a low output, say less than 30 cwt. per hour, is required over long periods. The main difference between them and standard cupolas is in the curtailed preheating space between the top of the bed coke and the top of the stack.

Chapter 6

PATTERN EQUIPMENT

THE subject of pattern equipment is one which covers a vast field, and in the limited space of one chapter one cannot include the whole of the tremendous range of patterns for castings that may vary in weight from a few ounces to 50 or 60 tons. Moreover, it would be unwise to lay down any hard-and-fast rule regarding the method of construction or design of any type of pattern equipment to be adopted by foundries in general, as each individual foundry is equipped with moulding plant of a type consistent with the class of casting being produced. Consequently the pattern equipment must be designed to meet such specific requirements as may suit the class of work upon which the foundry is engaged.

In this chapter, however, we shall deal with as wide a range of patterns as is practicable, including examples of equipment for the production of light, medium and heavy castings, and for this purpose the chapter will deal with practical applications concerning each type or class of equipment independently in the sequence as stated. As most readers will be aware, the subject of pattern equipment and moulding are so intimately allied that it is rarely possible to describe one without making frequent reference to the other, as there are almost as many essentials of pattern work learned in the foundry as there are in the pattern-shop. This will explain the many references to moulding practice, which will occur later. So intimately connected, in fact, are the operations of pattern mounting and moulding, that one of the finest assets of a good pattern fitter or moulder is the ability to form a rapid and reliable judgment as to the most efficient method of layout, and in this connexion it is frequently found that an experienced craftsman will see through a job at once, with an almost unerring instinct; but so many factors have to be borne in mind that it is almost unnecessary to say that this faculty can only be acquired by long experience.

MATERIALS USED FOR PATTERN MAKING

The variety of materials used in pattern construction covers a fairly wide range. It includes yellow pine, mahogany, and white metal, aluminium alloy, cast iron, brass, plaster of paris, and various proprietary compounds each of which possesses qualities peculiar to its respective character or nature. These qualities usually determine the choice of material for the many and varied types of pattern equipment.

Much can be said in favour of wood, although it is very susceptible to the influence of moisture. On this account it may appear as though wood is not a suitable material to be employed in direct and continuous contact with sand, which is necessarily always damp. Nor would it seem to be able to stand up to the rough usage incidental to the ramming and rapping which are necessary for moulding. However, there are several reasons why wood is used. In the first place, it is cheap and easily shaped; and, secondly, it is light and portable, and by the adoption of several precautions the evils incidental to its weakness and porosity may be largely overcome.

Yellow Pine. This type of wood, common to the majority of wood pattern-makers, has a wide field of application in the construction of patterns in general. It possesses characteristic features which make it invaluable for the construction of patterns or core-boxes. It is also reasonably cheap, readily available and tolerably permanent in form. Its use, however, for the construction of permanent production patterns for light castings should not be encouraged, as it is unable to withstand the severe service conditions likely to be met in the foundry.

Mahogany. This wood, unlike pine, is admirably suited for the construction of almost any type of pattern of reasonable dimensions, including loose patterns, master patterns, or even mounted production patterns. It is much stronger and more durable than the softer types of wood. It is in connexion with production patterns that mahogany has its widest field of application, as patterns in this material can be mounted either on wooden boards or metal plates to meet all normal requirements of hand or machine moulding. They can also be used on any type of moulding machine. Incidentally, its adoption for this class of equipment has its limitations, and, obviously, its choice must be governed to some extent by design and by the quantity of moulds required to be made from such patterns.

Economy in weight combined with speed in mounting for production are two distinct advantages of this type of pattern equipment, the former applying, of course, when manual effort is employed to withdraw the pattern from the mould, as in the case of small hand- or pneumatic-squeeze type of moulding. The advantages of the latter are economy in the cost of mounting and the saving of time taken to prepare the patterns for production. This fact assumes greater importance when speed of delivery of castings is of first consideration.

In some instances wood can be used to advantage as a base or major portion of a pattern in combination with metal, preferably a light alloy, the latter being used chiefly for the more delicate sections or for loose pieces. With certain exceptions, therefore, wood as a medium for general pattern construction has definite points in its favour as compared with metal, but its natural weaknesses prove it to be generally unsuitable for the construction of intricate pattern mountings when precision and accuracy of detail are to be maintained during long spells of service.

One of the most characteristic disadvantages common to this material is its tendency to warp. This is aggravated, more or less, by constant contact with damp sand, and by widely differing shop conditions, including steamy atmospheres, which are common in most foundries and which may be detrimental to patterns of a more fragile nature. Its inability to withstand the continuous abrasive action of sand serves, to some extent, to explain the reason for its rejection in favour of metal, particularly for such patterns as may be required for repetition work. In any case, however, only the most durable forms of timber should be used for wood production patterns.

CAST-IRON PATTERNS

Of the previously mentioned metals cast iron does, without exception, possess the wider field of application, and does, with few exceptions, possess all the more important qualities necessary for the construction of metal pattern equipment. Apart from its being the most common of metals, its popularity is further enhanced by its simple manner of working, an advantage not generally shared by the alternative non-ferrous metals. From the standpoint of strength it compares favourably with other metals, and is capable of taking a fine surface finish. It is also more resistant to the abrasive action of sand, an asset when the continuous production of castings with clean edges is necessary. Although the above remarks are mainly concerned with its virtues, it does, nevertheless, possess certain vices, the foremost of them being its excessive weight. This factor may assume serious proportions when the fatigue of manual operation is of paramount importance, as is often the case in the light castings industry. However, the fact that sectional thicknesses may not necessarily exceed ¼ in., subject, of course, to the exercise of reasonable care, lends, even to this material, a fair amount of elasticity of application.

BRASS PATTERNS

The use of brass in pattern equipment is largely confined to the actual pattern, or section of pattern, only, and not to the base upon which it is mounted. The brass patterns may be mounted on plates of either wood, cast iron, aluminium, or steel, and such patterns enjoy a considerable length of life in service. This is due in no small measure, to the high physical strength of brass and also to its semi-ductile nature. It is also extensively

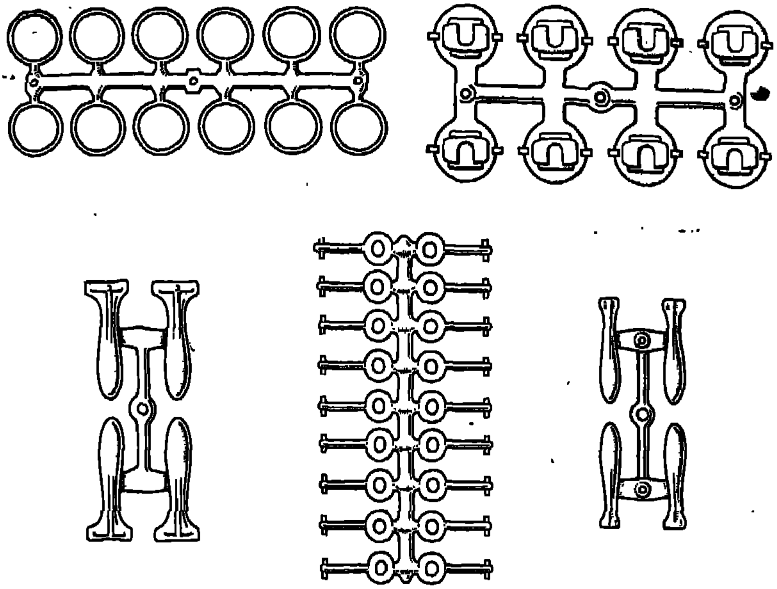


FIG. 6.1. *Five groups of brass spray patterns for light castings.*

used for the construction of spray patterns, such as are seen in Fig. 6.1. Its popularity for this class of pattern equipment is, no doubt, influenced to some extent by the ease of construction by soldering, as such patterns are necessarily of unit construction, and are usually subject to much more severe service conditions. It stands up extremely well to rapping, which is incidental to the usual moulding practice when such methods of production are employed. Another sound reason why brass is used for this type of pattern is that it can be used successfully in the construction of the smallest types or designs of patterns similar to those illustrated in Fig. 6.1, the size and section of which are beyond the reasonable practical limits of ferrous metals. Its ability to take a fine surface finish excels that of cast iron, whilst its immunity to attack from rust and its resistance to the effects of chill are advantages not possessed by cast iron. These features prove it to be ideal for the construction of equipment of exceptionally light section, whereas in cast iron such patterns would be too fragile, and very difficult to finish by filing. The quality of brass required for patterns is not a factor of great importance, and for this reason common scrap can be used quite safely. If, however, it does need improvement in any particular characteristic it can be "toned up" by the addition of a proportion of one or a combination of its common constituents.

ALUMINIUM ALLOY

Owing to its exceptional lightness this metal has an extensive field of application, especially when fatigue of constant manual effort is taken into consideration. Like cast iron, it can be applied exclusively for almost any type of pattern equipment, including rolled plate or cast plates to be machined for mounting purposes, single-sided plates for hand or machine moulding, or loose patterns. Although the major advantage of this metal is its low ratio of weight to volume, it also shares the advantage of other non-ferrous metals regarding immunity from the effects of rust and chill, and is reasonably resistant to the abrasive action of sand. The type of metal used in the casting of pattern equipment is a common alloy which is produced in ingot form and conforms to the following analysis: (3L5 Alloy) zinc 12½ to 15 per cent, copper 2 to 3 per cent, iron and silicon 1·5 per cent, the remainder being aluminium. Precautions in the working of this metal are necessary to combat the danger of pronounced liquid shrinkage in heavy sections. This, in some instances, involves a drastic change in the technique of running and feeding, and in some cases necessitates the application of chills or denseners. The pouring temperature should also be carefully controlled, 700 deg. C. being reasonable for small patterns such as are illustrated in Fig. 6.2. These, incidentally, are a type of plate used for snap flask moulding on small pneumatic- or hand-squeeze moulding machines.

WHITE METAL

Although this metal is not so widely used for the construction of actual patterns as any of the previously mentioned metals, due, probably, to its softer nature and lower resistance to abrasive wear, it is invaluable for the lining of intricate stripping plates. This latter application is the means of effecting an appreciable saving in time and labour in pattern mounting. Two of the main characteristics of white metal which have a

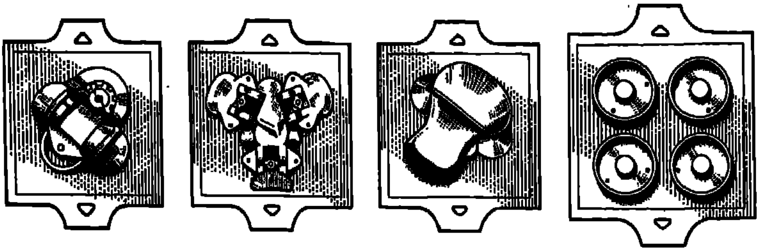


FIG. 6.2. *Typical plates used for snap-flask moulding. These plates are double-sided and made of aluminium.*

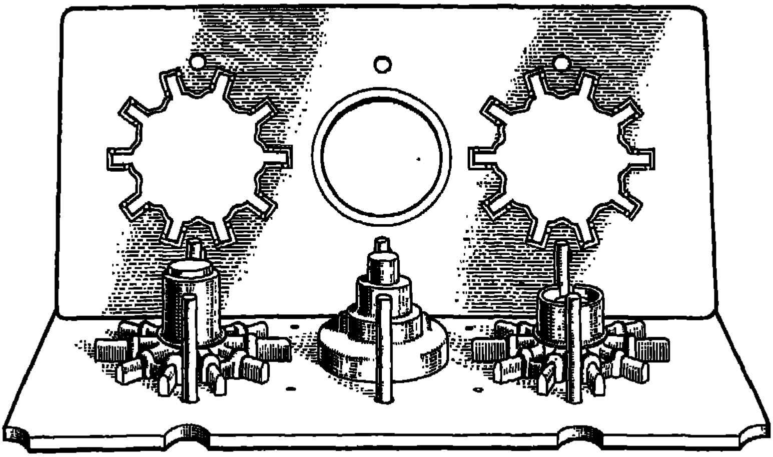


Fig. 6.3. *Application of white metal in the lining of stripping plates. The rim or lining of metal is seen on the stripping plate in the top portion of the illustration, whilst below are shown the finished patterns.*

great influence on its selection for this class of work are its low melting point (approximately 260 deg. C.) and its immunity from the effects of chill. Both these factors enable it to be successfully poured into an unlimited variety of intricate shapes and contours. The substitution of lead as an alternative is not generally recommended owing to its exceptionally soft nature. It can, however, be added to white metal in small proportions to improve its ductility. Fig. 6.3 is a really first-class example of the application of white metal in the lining of stripping plates.

PLASTER OF PARIS

This material, which can be obtained in several grades, has a very useful field of application, especially in the construction of patterns or core boxes of relatively small dimensions. It can be used to great advantage to reproduce plaster casts of undercut sections of patterns, or awkward projections, a plaster core box being afterwards produced from the block. One essential—speed—must be observed when preparing this compound, as it solidifies, or sets, very rapidly. After pouring, the plaster cast may be air dried or placed in a warm atmosphere if drying off is required to be accelerated. Certain advantages over this original material have been claimed in recent years by various proprietary brands of pattern compound. These include such features as improved physical strength, smooth surface finish, the ability to reproduce clearly defined contours and impressions and less liability to develop surface defects, or perish after prolonged use.

USE OF COMPOUNDS

Although these proprietary materials are employed to some extent for oddside impressions, they have a wider general application in the construction of actual pattern plates. This is because they do not involve the evils of expansion or contraction—a unique advantage over metals. Such compounds can be applied to great advantage in the construction of twin match plate patterns, which may be cast in iron or steel frames. This serves the dual purpose of strengthening the compound block and of locating the combination patterns. The use of pattern compounds as a medium for the complete construction of twin match plates has certain limitations, and is influenced in some respects by the design of patterns under consideration which, if of a fragile nature or of very light section, may necessitate the adoption of one of two alternative methods.

The first is usually in the form of one-half impression in compound, the opposite half being a combination of metal half-pattern embedded in compound. The obvious benefit of the method when compared with twin plates consisting exclusively of compound will be appreciated when patterns such as those illustrated in Fig. 6.4 are encountered. The second method referred to is the employment of combination patterns for both halves of the twin match plate. This invariably involves the use of two patterns, one being smoothly finished on the surface which forms the top impression, the other being finished on the opposite surface, which forms the bottom impression. The exercise of great care by the pattern moulder is essential in the production of this type of pattern equipment, as its success is dependent on a perfectly prepared mould.

Such types of pattern equipment, whether they be produced exclusively of compound or of a combination of metal pattern embedded in compound, can be successfully adopted when the subsequent procedure is the employment of hand ramming or squeeze type moulding machines. For use on jolt or jolt-moulding machines, however, they compare unfavourably with pattern plates of all-metal construction, mainly because they lack the physical strength necessary to withstand the severe service conditions imposed on them.

Although it has been stated that plaster of paris and other proprietary compound materials are admirably suited for the construction of permanent oddside impressions, in some foundries their employment is the exception rather than the rule, and sand is used for this purpose. Such a material, especially if it is of the naturally bonded type, has certain service limitations. These are due mainly to its friable nature, particularly when being subjected to repeated exposure and to its inability to withstand the wear and tear of normal moulding practice. Under the best of conditions it can only be of a semi-permanent nature. However, a great improvement can

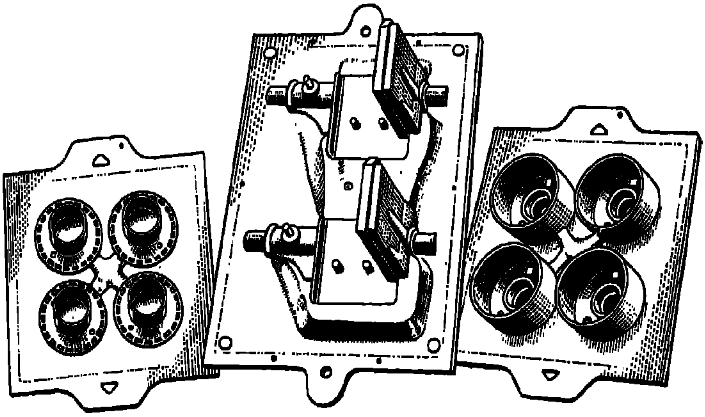


FIG. 6.4. *Metal half-patterns embedded in plaster. The thin projections would be very fragile if made of compound.*

be effected by the addition of either a proportion of cement or vegetable oil as a binding agent. When baked, or dried, these additions produce a good hard matrix.

Oil sand as a medium for the making of oddside impressions has few equals from the point of view of simplicity of application, and exceptionally good results can be obtained, especially if an extra amount of oil is used. This should be in the neighbourhood of double the amount used for a normal core-sand mixture. This material, when thoroughly dried, makes a good hard and waterproof oddside impression, and can, subject to the exercise of reasonable care in service, be used to produce several hundreds of moulds.

PATTERN LAYOUT

From the production standpoint, the correct layout of pattern equipment is absolutely essential, and each individual pattern, or set of patterns, that has to be mounted usually requires careful consideration and forethought, if one is to obtain the greatest economy in moulding time consistent with the maximum production of good castings. However, these two important objectives are not attained in the majority of cases, at any rate, unless the layout under consideration is studied from all points of view likely to affect or prejudice the final product. In this respect the following points may be worthy of note. In the first place, the design of pattern layout involving a number of patterns should be on symmetrical lines, or, in the case of a single pattern, centrally disposed to the plate. This point is specially stressed in the case of pattern equipment when the operation of

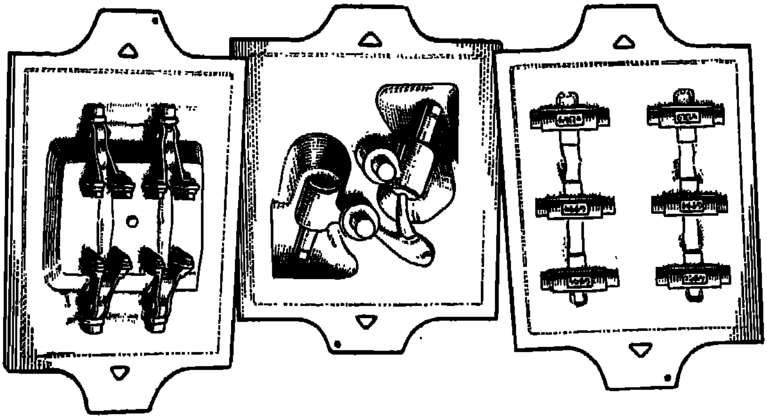


FIG. 6.5. *Well-balanced layout of pattern plates. The object is to balance the weight in order to assist the operator when drawing the pattern from the mould, and it assumes greater importance with increasing pattern depth.*

withdrawal from the mould is by hand, as the correct balance of the plate is of vital importance to the operator. An illustration of a well-balanced layout is shown in Fig. 6.5.

Although the problem of correct balance is important, it need not necessarily be the governing factor in every layout, even where manual effort is concerned, as, obviously, the position of the gates, down runners, core prints, and machined surfaces must all be considered in the sequence of importance as represented by the specific requirements of each individual type of casting. As regards in-gates, these may vary considerably both in size and position, as the correct gating necessary in the production of castings in malleable iron, light alloys and non-ferrous metals is appreciably different from those usually employed on grey iron castings. This will be noted in Fig. 6.6 which illustrates a comparative group of castings in cast iron, malleable iron, bronze and aluminium. With regard to down runners, there is a certain amount of flexibility of position which should be carefully considered from the standpoint of reasonable accessibility in order to facilitate the operation of pouring. An illustration showing several examples of patterns with runners in accessible positions for pouring, even when closely packed on the moulding floor, is shown in Fig. 6.7. The position of core prints relative to the adequate provision for the unrestricted flow of gases into the atmosphere is, of course, of great importance. These gases, which are generated when pouring, may cause faulty castings if adequate provision for this escape is not made.

The function of core prints is to provide the correct location of the

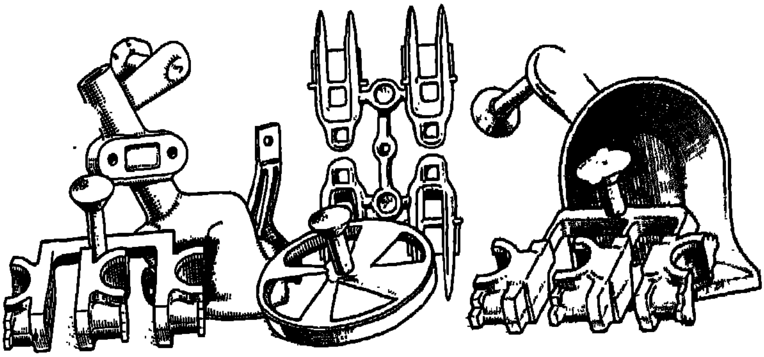


FIG. 6.6. *Group of castings in cast iron, malleable iron, aluminium and bronze, showing different styles of ingate.*

core, and in most cases to anchor the core during the operation of pouring. Its position in relation to the actual pattern may be either vertical, horizontal, or it may even constitute the major portion of the pattern such as a water-jacket for a cylinder or cylinder head. In the case of the vertical core, venting is invariably effected by a vent wire, or in the case of larger cores by a tube pushed through the top or bottom prints. In the latter case it must be connected by a vent running under the box or flask. The inclusion of such facilities as an integral part of the pattern layout can be of extreme value in the subsequent mould productions. An example of vent pins embodied in pattern layout is seen in Fig. 6.8. This vent pin is attached to the end of a vertical core, which forms the bore of a small petrol engine

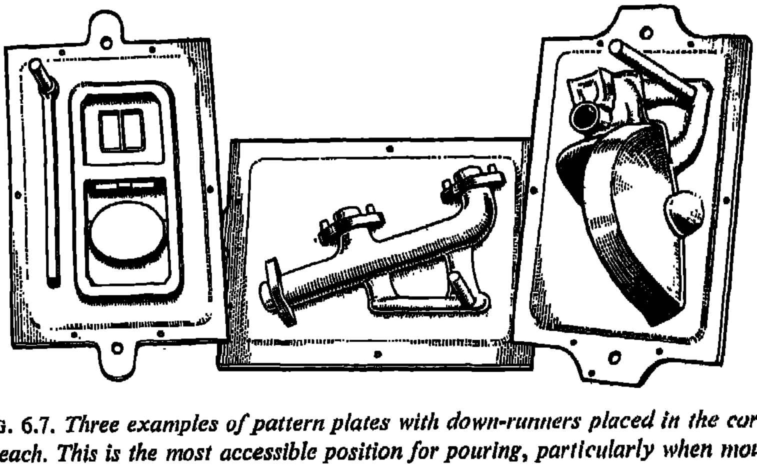


FIG. 6.7. *Three examples of pattern plates with down-runners placed in the corner of each. This is the most accessible position for pouring, particularly when moulds are closely stacked on the floor.*

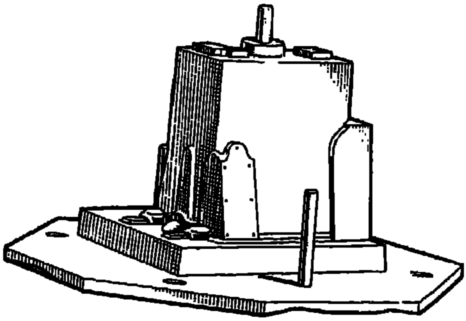


FIG. 6.8. *Embodiment of a vent pin in the main core of a pattern layout for a small vertical engine cylinder. The pin is seen projecting from the top print of the core.*

cylinder. The provision of adequate venting facilities in pattern layout, involving horizontal core prints, is reasonably simple, but every care should be taken to ensure their efficiency, as a horizontal core is much more liable to give trouble than one in a vertical position, due in a large measure to the fact that the molten metal must lie on the core without the creation of turbulence in the metal, otherwise a blown casting may result. The type of material generally used to form the vent channels is half-round section brass strip, the size of section being dependent on the core concerned, or similarly the volume of gas likely to be generated. A layout involving this method of venting is seen in Fig. 6.9. In the case of cores which constitute the major portion of the pattern, or water-jacket cores, the method and arrangement of adequate venting facilities must necessarily be governed by the design of the pattern under consideration. In some instances the prints of such cores are allowed to extend through the side of the moulding box and by so doing provide excellent means of venting. A layout for the production of a horizontal petrol engine cylinder showing core prints extending through the side of the moulding box is seen in Fig. 6.10.

The importance of machine faces and their relative position in any proposed pattern layout cannot be too highly stressed, and wherever practicable such layouts should be designed with the object of moulding such surfaces in the bottom, or drag, half of the mould. The illustrations in Figs. 6.11 and 6.12 which, incidentally, are patterns of a circular saw table, are a type of casting requiring a perfectly clean machined surface, and for this reason could not be moulded the easiest way, namely, with the flat face uppermost. Obviously, the moulding conditions are rendered more difficult when the flat face of the pattern is in the drag half of the mould, and the more difficult ribbed face of the pattern in the cope.

SPRAY PATTERNS

As the description implies, this type of pattern equipment in general application usually consists of a number of relatively small patterns

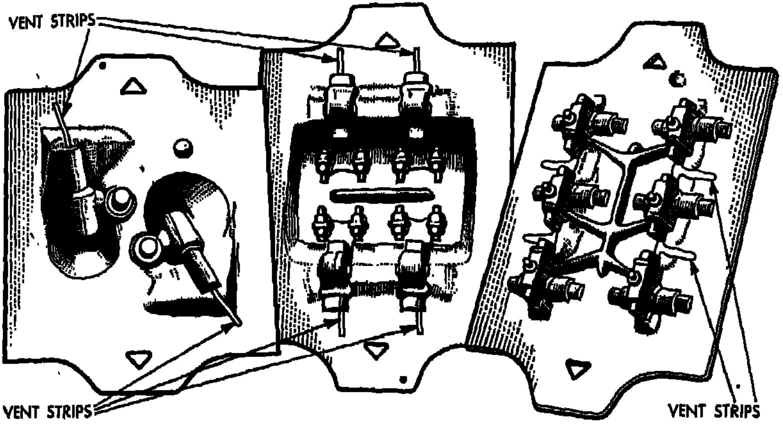


FIG. 6.9. *The correct position of vent strips (made of half-round brass strips) on three types of pattern plates.*

assembled together by means of the spray runner, the whole being of single unit construction. Such equipment enjoys great popularity in foundries engaged in the production of malleable castings. An obvious explanation for its adoption in this class of work is the exceptionally light character of many of the castings involved, whilst another definite advantage of this type of equipment is the elimination of the evils of a second contraction on the patterns so constructed. As stated previously, patterns intended

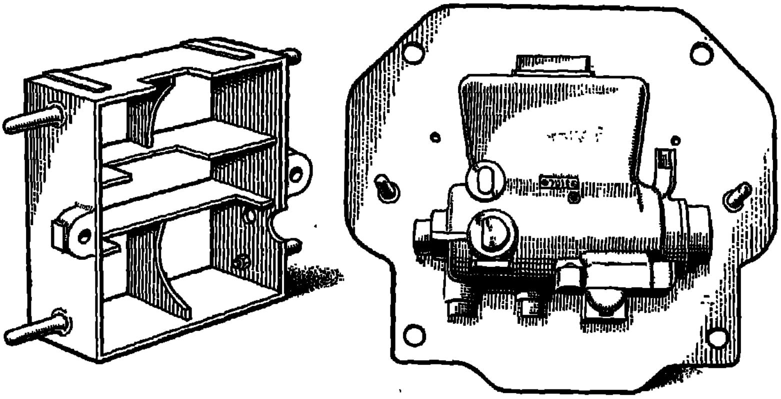


FIG. 6.10. *Pattern plate and moulding box cut away to fit over the two main core prints for a small horizontal engine cylinder. This facilitates anchorage of the main body core, and provides unrestricted escape of gases from the core.*

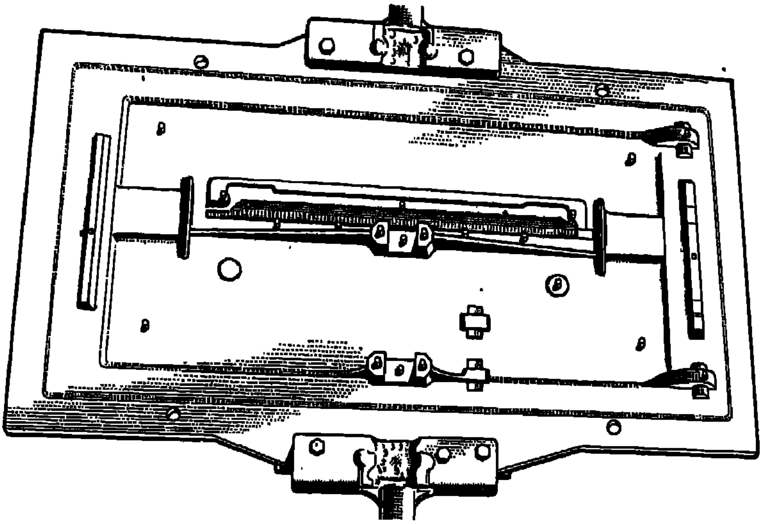


FIG 6.11. *Complete pattern plate for a circular-saw table, mounted so that when moulded the ribbed underside of the finished casting is in the top or cope part.*

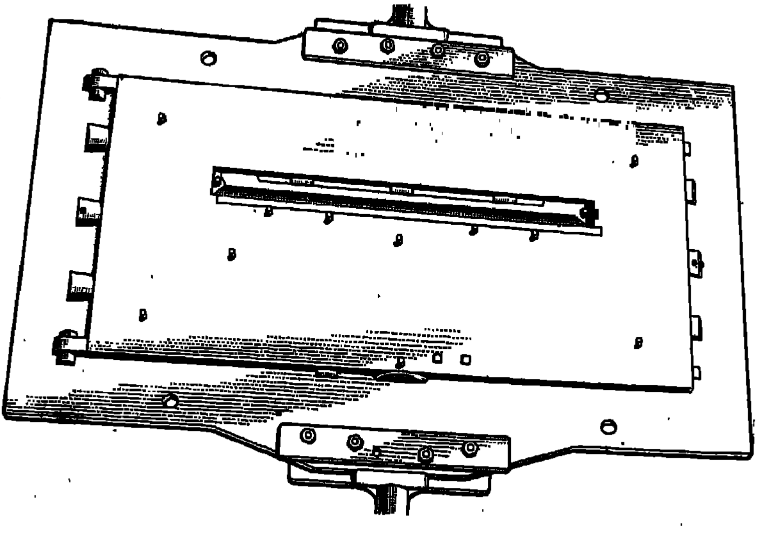


FIG. 6.12. *The opposite side of the circular-saw table pattern plate shown in Fig. 6.11. This surface has to be clean after machining, and is best cast in the bottom or drag part of the mould.*

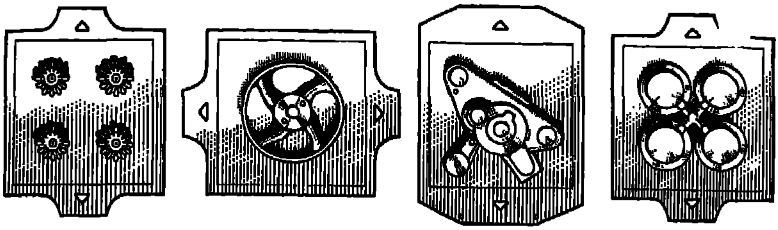


FIG. 6.13. *Small patterns mounted on flat plates.*

for this method of production are made from non-ferrous metal, usually brass.

TYPES OF PLATES

The pattern plates illustrated in Fig. 6.13 represent a mounting in its simplest form, namely, the split pattern or flatback. These are mounted one on either side of a plate, in the former case, and a complete pattern on one side only in the latter case, whilst the group in Figs. 6.14 and 6.15 are complete double-sided plates in cast iron. As will be observed, the pattern plates in Fig. 6.15 have joint contours of irregular shape which extend to the outer edges of the plates and consequently involve the use of special moulding boxes. Although this type of pattern plate has a limited field of application in the majority of foundries, nevertheless it is a type extensively adopted by foundries specializing in the production of certain classes of light castings, such as stoves, grates, domestic appliances, and so on. Its popularity for the production of this class of work is due, in some measure, to the complexities of design which are encountered in these various specialized products, especially those used in the production of stove and grate castings, which would, if moulded in boxes having level joint faces, not only involve the use of a great deal more sand but would also mean lifting deep pockets or cods. These are both serious factors when making repetition light castings. Regarding the size of such pattern

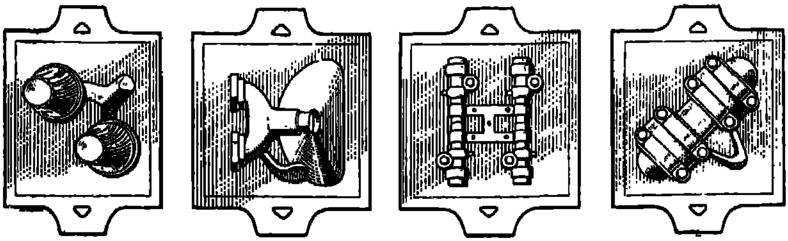


FIG. 6.14. *Double-sided patterns in cast iron.*

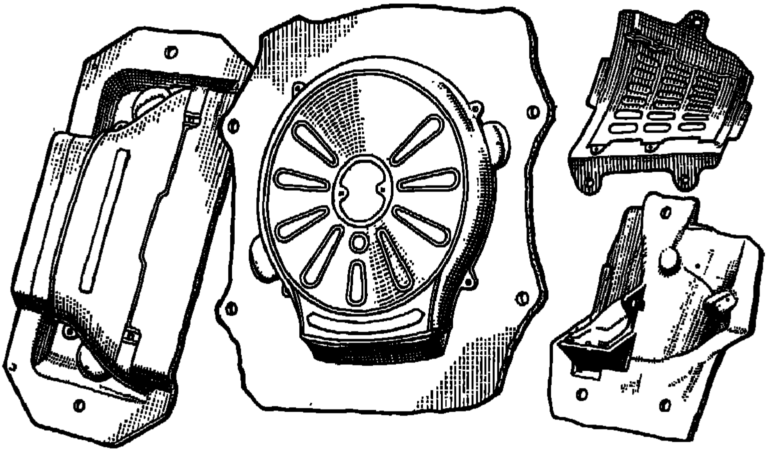


FIG. 6.15. *Double-sided pattern plates of irregular contour for use with special moulding boxes. Their sizes range from 14 in. × 14 in. to 30 in. × 30 in.*

plates, the useful limit consistent with safety is a rather debatable point, as, obviously, their strength cannot be increased by suitable ribs as in the case of a single-sided plate but can only be attained by increasing the sectional thickness of the whole plate.

LARGE DOUBLE-SIDED CAST PLATES

The following sections can be safely recommended for cast iron pattern plates of the variety of sizes appended.

Area (*in.*)	10 × 10	12 × 12	14 × 14	18 × 18	30 × 30	36 × 36	60 × 60
Thickness (*in.*)	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$

An example of the last size is illustrated in Fig. 6.16, and various stages in the moulding of this pattern plate are shown in Figs. 6.17–20. A brief description of the method of moulding such a pattern plate, which, incidentally, closely resembles the practice adopted to produce the smaller types, together with a few essentials incidental to their successful production, may be worthy of note especially to foundrymen less familiar with this type of equipment. In the first place, it is absolutely essential to use a moulding box which has good fitting, flat joint faces, preferably machined. These faces provide the level which subsequently determines the correct elevation of the final pattern setting. The box should also be fitted with good pins, the tolerance allowance being kept to a minimum, as the accurate registration of the subsequent casting produced from it is entirely dependent on this. The length of the pins is determined by the depth of the pattern under consideration, and it is necessary that they should be long

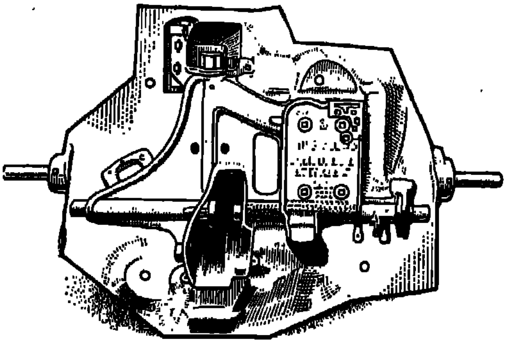


FIG. 6.16. *Complete double-sided pattern plate (60 in. × 60 in.) with irregular joint line. Stages in the moulding of this pattern plate are shown in Figs. 6.17–20.*

enough to provide the means of steadying the cope mould until it is completely clear of the pattern in the drag. Assuming, therefore, that the moulding tackle conforms with the high standard of efficiency so essential for this class of work, the sequence of moulding operations is as follows: First of all the cope is laid in position and rammed solid with sand and strickled perfectly level.

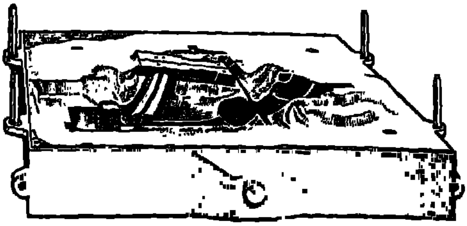
The pattern is then placed on in the desired position. Should it be necessary to bed the pattern in the cope in order to allow the level of joint to conform to the centre line of pattern, as in this particular case, sand should be taken out roughly to the shape and depth as required to bed the pattern firmly in the exact ramming position as shown in Fig. 6.18. The drag is then rammed up, turned over and the cope is removed.

The preparation of the pattern joint is the next operation, and is one the importance of which cannot be too strongly emphasized, especially if it is of an irregular contour. The exact contour is determined by the special cope box pattern, or even a special cope box which is subsequently to be used for actual mould production from the pattern plate under consideration. This is placed in position over the pattern and bedded down until the joint face of the cope conforms exactly to the centre line of the pattern or to any predetermined level likely to facilitate the subsequent moulding operations when the plate is in production.

After completion of the joint, the ordinary cope is rammed up and lifted off. The next operation is the building up of the joint to the desired shape and thickness. The first item, that of shape, is again determined by that of the special box to be used in production.

A liberal allowance should be made for the plate to extend 2 or 3 in. outside the special box at any point with special provision of lugs for pin holes and extensions for trunnions. The thickness of the plate is influenced, to a great extent, by the area involved, a guide to this being given on page 196. The operation of building up the plate is aided by strips of wood of the desired plate thickness. An illustration of pattern and mould prior to closing, with plate thickness partly built up, is shown in Fig. 6.19,

FIG. 6.17. *Cope mould of pattern prior to closing. Note disposition of the four down-runners which enable the plate to be poured quickly.*



whilst Fig. 6.20 represents the special cope and drag. Although the main outlines of the plate are determined by the shape of the special boxes to be used in production, there are two important positions which must be left to the discretion of the pattern moulder.

These are the usual positions for the trunnions, which necessarily must both be on the same plane or level, and should be of sufficient width to allow a reasonable margin for the metal pattern fitter to ascertain the correct point of balance prior to fitting trunnions. This is very important, especially on large plates of irregular shape which may weigh upwards of 6 to 10 cwt. Such a plate pattern may be very troublesome and even dangerous to the operator or moulder when it is in production on a turnover machine.

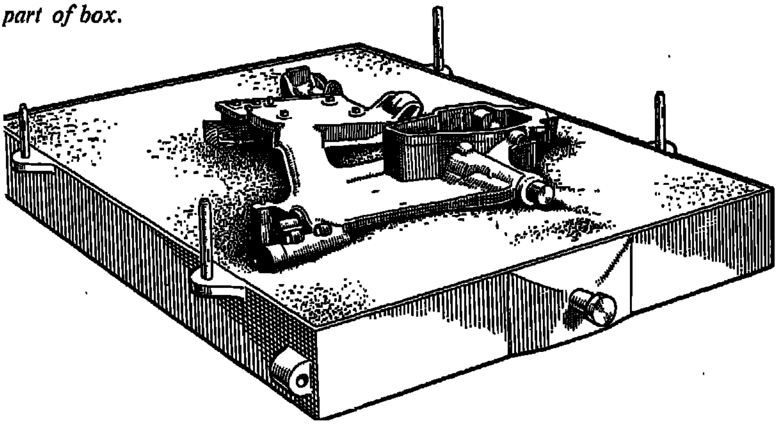
SMALL DOUBLE-SIDED CAST PLATES

The method of making this type of plate is closely allied in principle to that described for large plates, the only difference being the process of building up the plate thickness. This is invariably done with a standardized template or frame, the template conforming to the type or types of moulding boxes, or snap flasks employed in the production of any particular class of casting. A group of templates of various sizes from 10 in. × 10 in. to 12 in. × 18 in. is seen in Fig. 6.21, and an illustration of small double-sided pattern plates for use in conjunction with adaptor frames is shown in Fig. 6.22.

SINGLE-SIDED PATTERN PLATES

The adoption of this type of pattern equipment is, to some extent, influenced by one or both of two principal factors, assuming, of course, that they are to be worked on some type of moulding machine, or at least in some form connected with quantity production. In the first place, if the moulding equipment is of the pin lift type, one side of the plate must, of necessity, be flat and preferably machined. Secondly, if maximum production of moulds is of primary importance the pattern plates may be worked in pairs simultaneously, one producing the cope, the other producing the drag. Patterns of this type can be produced by two methods—one by casting a complete pair of plates by the split mould process,

FIG. 6.18. *Pattern rammed up in drag part of box.*



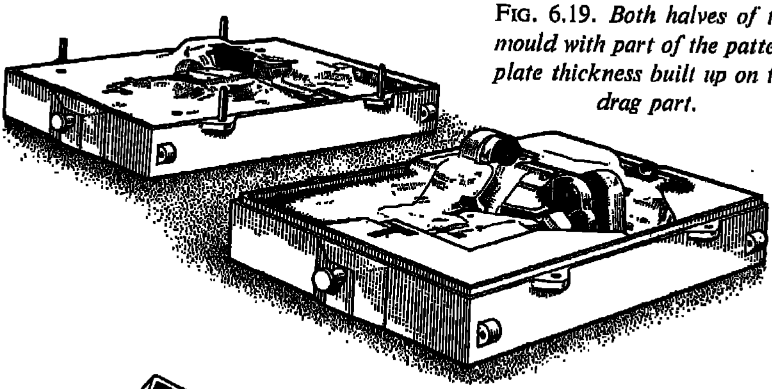


FIG. 6.19. *Both halves of the mould with part of the pattern plate thickness built up on the drag part.*

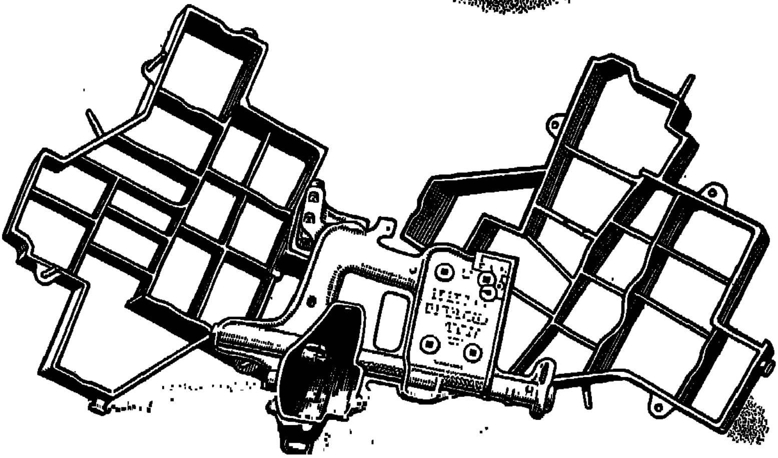


FIG. 6.20. *Special box parts and the final casting produced.*

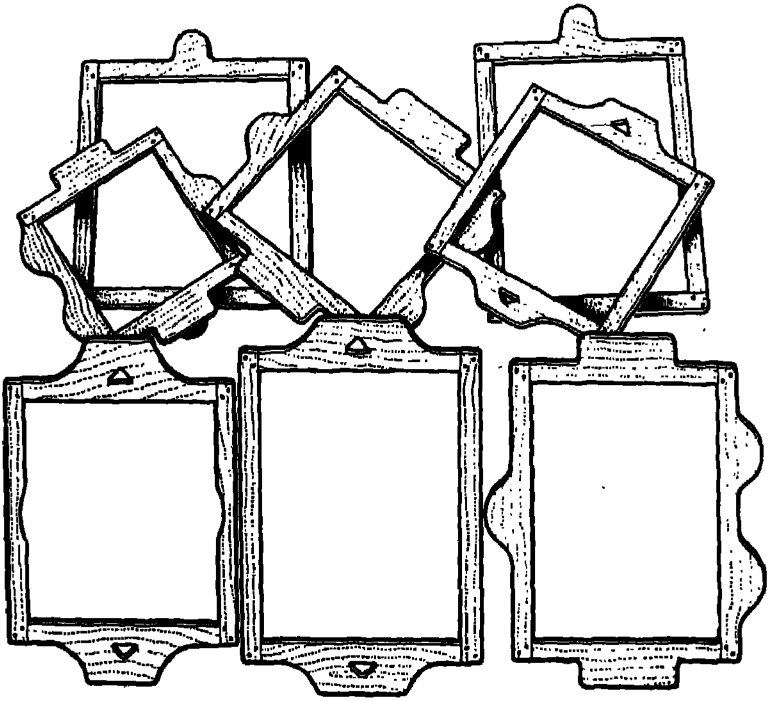


FIG. 6.21. *Templates for use in the production of double-sided cast pattern plates. Those with triangular pinholes are for patterns moulded in snap flasks.*

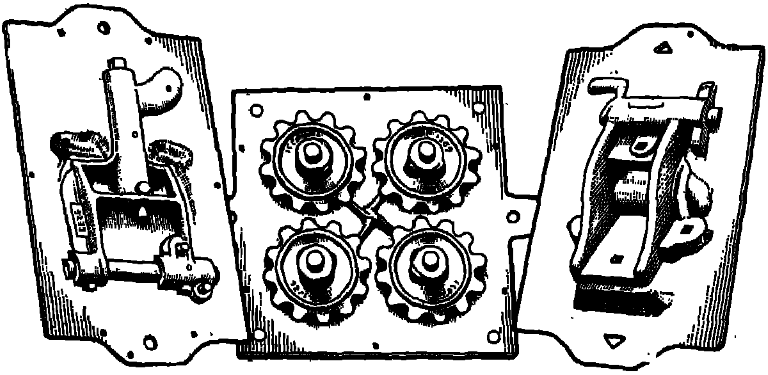


FIG. 6.22. *Typical double-sided cast pattern plates for use with adaptor frames. The drag or bottom side of the pattern is shown in each case.*

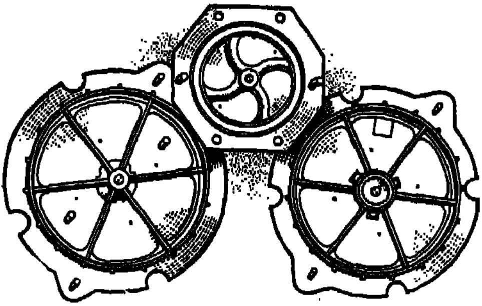


FIG. 6.23. *Group of cast-iron wheel patterns mounted on machined baseplates. This method is used for dimensional accuracy when the production run is sufficient to justify the initial cost.*

and the other by mounting patterns or building sections of patterns on machined baseplates. The advantage of the latter method is obviously that of dimensional accuracy, which, in many cases, is essential when castings must be produced to fine tolerance limits. It is, however, an expensive method of construction and one which, in many cases, must rely on large quantity requirements to justify its adoption. Fig. 6.23 shows a group of cast-iron wheel patterns mounted on machined baseplates.

SPLIT MOULD PROCESS

This method of pattern plate production is both quicker and less costly than other methods, and is capable of giving exceptionally good results, subject, of course, to the exercise of extreme care on the part of the pattern moulder. A brief explanation of the principles of this method may be of interest to those likely to consider its adoption. In the first place it is necessary to use a pair of moulding boxes together with an extra two copes, the complete set of four parts to be interchangeable. The moulding operations, for which the complete pair of boxes is used are similar to those already described in moulding a double-sided pattern plate, but instead of closing the two half moulds they are each treated as drag moulds which, in turn, are covered by the two extra copes previously rammed up on a flat plate or board. This may, at first, seem impracticable if the joint faces of the original pattern mould are not flat, as is the case in many instances, such conditions being governed by the design of pattern, which may involve a joint of irregular contour. In such instances, the irregularities that occur may be overcome by two methods, the choice of either being influenced by the individual problem under consideration.

The first method, which, incidentally, is limited to reasonably simple joint contours, involves the building up of the lower points of the joint face to a height allowing the desired plate thickness to cover the original joint at its highest point. The mould then has a flat joint and conforms to the flat face of the cope. It may be found, however, that in raising the joint

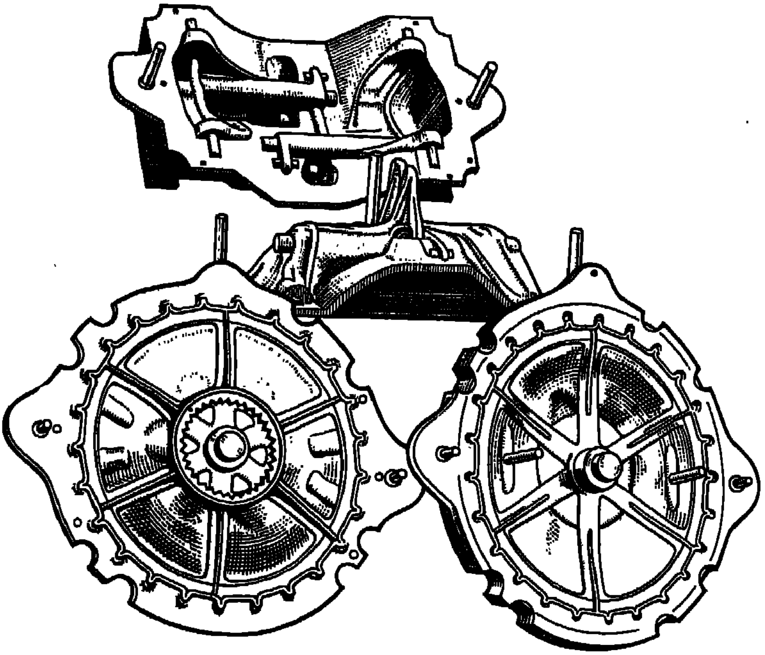


FIG. 6.24. *Two pairs of pattern plates produced by the split-mould process. The top pair is a good example of coring out a very awkward joint contour.*

face to a common level the thickness of the plate in some areas, especially that immediately over the pattern, has increased beyond reasonable limits. Where this occurs, cores may be shaped and fastened to the cope when their correct position has been ascertained. By this means the sectional thickness of the pattern plate can be controlled within reasonable limits. The second method, which can be applied with success under the most awkward conditions, is that of using core blocks which can be sawn or filed to any shape to conform to either the joint contour or to lighten out any area or section of the plate where excessive masses of metal are likely to be detrimental to the pattern in general. Means of ascertaining the correct registration of the twin plates when in production is an important point and one which may appear to involve careful marking out by the metal pattern fitter.

There is, however, a very simple alternative to this practice. It involves the use of small circular disks 1 in. in diameter. These are countersunk on either side exactly in the centre. The number required is four and these may be pressed into the joint of one pattern mould, preferably one in each corner, prior to ramming up the cope. By this means the impression of the

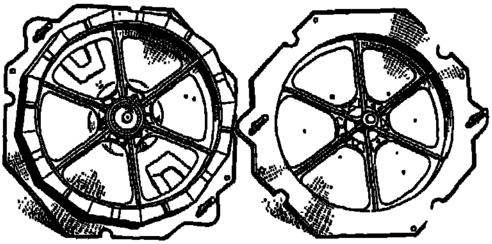


FIG. 6.25. *Single-sided pattern plates produced by the split-mould process. The pair weigh ½ ton and measure 54 in. in diameter.*

disk and central countersink are transferred to both halves of the pattern mould, and provide true location spots for drilling the plates. After the holes are drilled, the patterns are placed together and held in position by four turned pins which should pass through the holes in both pattern plates, after which the required holes are drilled through a jig which conforms to the moulding-box pin centres. A group of medium size pattern plates produced by this process is illustrated in Fig. 6.24. Those in Fig. 6.25 are actually larger examples, although, for convenience, the illustration has been very considerably reduced. The pair of patterns weigh approximately half a ton and measure approximately 4 ft. 6 in. in diameter.

ADAPTOR FRAMES WITH DOUBLE-SIDED PLATES

Pattern plates of the double-sided type, similar to those illustrated in Fig. 6.22, whether composite cast plates or mounted pattern plates, are very popular in foundries engaged in repetition production when hand moulding methods are employed and, in many instances, where small squeezer types of machines are used. Beyond this, however, their limit of application would appear to end, especially where the moulding machines are of the jolt turnover type. Such, however, is not the case, as this type of pattern can be used on such machines in conjunction with an adaptor frame. The function of the frame, which must correspond in size to that of the moulding boxes in use on any particular machine, is that of providing a machined-faced receptacle for the pattern plate, and must have a depth slightly in excess of the deepest pattern likely to be used. This excess in depth is necessary to keep the pattern clear of the jolt table (see the chapter on Moulding Machines).

The adaptor frame is designed with eight lugs on the top face and two lugs on the bottom face. The bottom lugs are at each end of the frame, and are used to bolt it to the jolt table, whilst those on the top face serve a dual purpose; two of them are in a central position at each end of the frame, where they provide the means of locating the pattern plate; the remaining six are equally disposed round the frame to provide effective facilities for holding down the pattern plate during the moulding operation.

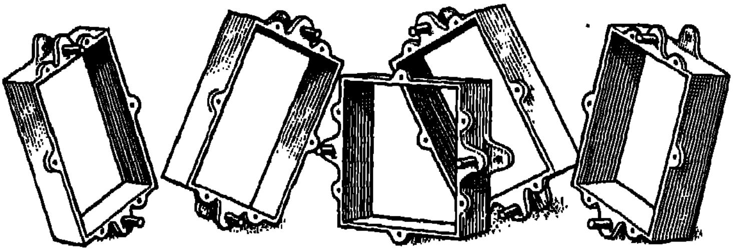


FIG. 6.26. *Group of adaptor frames for use on jolt-squeeze turnover machines. The outer examples are 12 in. × 18 in. and the centre one 15 in. × 15 in.*

Examples of several sizes of adaptor frames are seen in Fig. 6.26. Fig. 6.27 shows an adaptor frame and pattern assembled on the table of a jolt squeeze turnover machine.

It must be pointed out that the adaptor frame method requires moulding machines of the deep draw type, as the frame depth reduces the useful distance between the jolt table and the press head. Nevertheless, the small extra cost involved is more than justified when the substantial economies of pattern plate production are taken into consideration.

DOWN RUNNERS AND SPECIAL PRESS PLATES

It may be interesting to note that all illustrations of pattern plates used on machines of the jolt-squeeze turnover type are fitted with tapered runner pins, also riser and vent pins when necessary. In addition, each pattern has a special press plate with a clearance hole drilled in a position corresponding to that of the runner pin and a small pouring basin fitted to it. This special plate is bolted to the

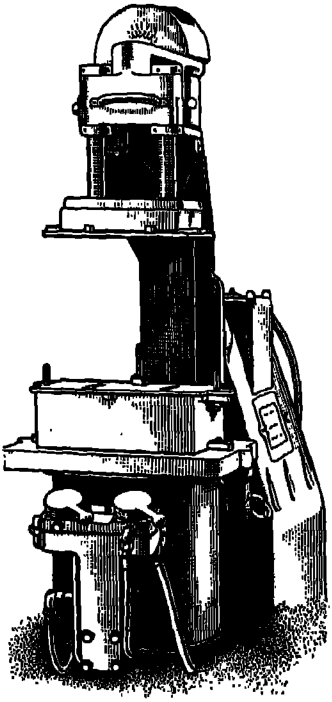


FIG. 6.27. *Double-sided pattern plate mounted on adaptor frame on jolt-squeeze turnover machine.*

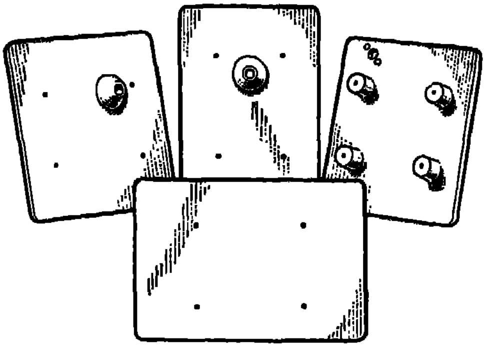


FIG. 6.28. *Group of press plates, all of which produce the necessary pouring basin. The lower one is for use with drag part moulds.*

press head of the machine in a position which allows it to correspond accurately with the inside of the moulding box, and any pins likely to be fitted to same during the squeezing operation. The clearance allowance between the outer edge of the press plate and the moulding box is ¼ in. The advantage gained by using a special press plate in conjunction with patterns fitted with runner pins results in the production of cope moulds complete with down runners and pouring basin in one cycle of operations. An illustration of a group of press plates is seen in Fig. 6.28, and in Fig. 6.29 a pair of cope moulds complete with down runners and pouring basin.

STRIPPING PLATES AND THEIR USE

The use of the stripping plate is not essential in every case in which it is employed, but it does, without question, simplify the operation of moulding in every instance. Its use is at times almost indispensable where moulding machines are exclusively of the pin lift type, especially where the patterns are of intricate design. It is also an important feature in pattern equipment when two or more moulds are rammed simultaneously on pin lift machines, such as those illustrated in Fig. 6.30, but could successfully be dispensed with by the introduction of turnover moulding machines, as

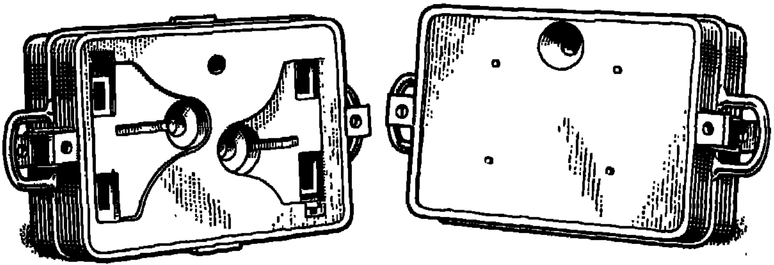


FIG. 6.29. *Pair of cope moulds, complete with down runners and pouring basin, produced in one operation.*

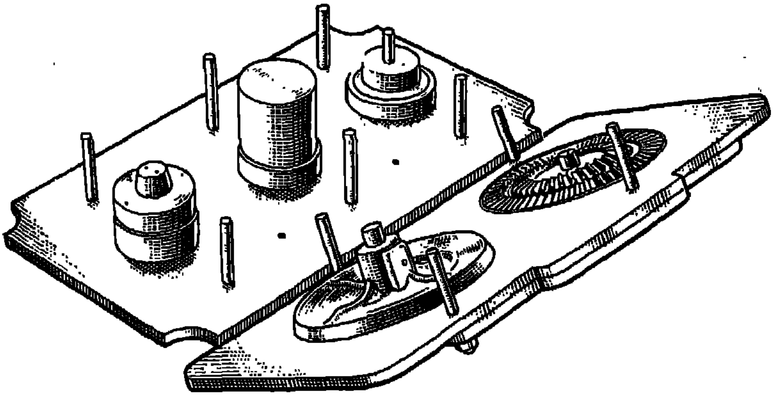


FIG. 6.30. *Two stripping-plate patterns for production of two or three moulds respectively, in one operation.*

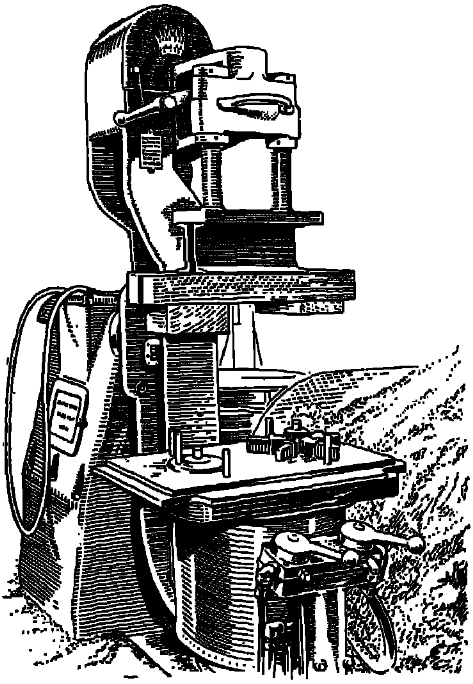


FIG. 6.31. *Turnover moulding machine, with pattern layout for the production of two moulds (cope and drag) in one cycle of operations without the aid of a stripping plate.*

shown in Fig. 6.31. Consider now the production of various types of gear wheels including straight, helical and spiral toothed gears similar to those illustrated in Fig. 6.32. In each instance the stripping plate is an essential feature, the ordinary spur wheel being a fairly common example, involving the simple movement of lowering the pattern through the stripping plate by means of a plunger to which is connected a small hand lever.

Helical and spiral gear patterns, however, require a very different mechanism to actuate their withdrawal. This can be accomplished by two methods, the first being that of mounting the pattern in a manner which allows it to rotate freely on a centre spindle so that the twisting movement necessary on withdrawal is done by the

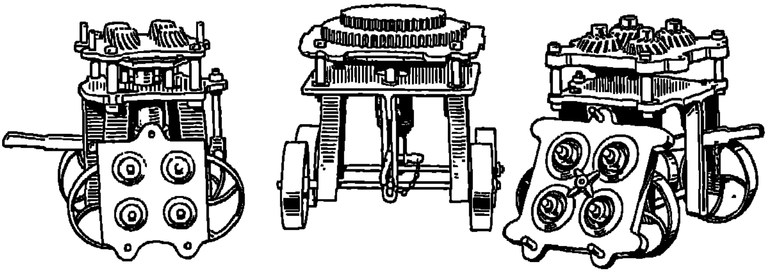


FIG. 6.32. *Group of stripping-plate machines for production of various types of gear wheels.*

stripping plate as the pattern is lowered on the table of the machine.

The second method is similar, with one exception, this being the addition of a small spring, one end of which is fastened to the spindle, and the other end to the pattern. Before fitting the stripping plate to pattern the latter is twisted until the spring is in tension. This causes the subsequent twisting action of the pattern to be spring-loaded and, therefore, positive. The function of the stripping plate in this instance is that of controlling the amount of movement during the operation of withdrawal. Although the latter method involving spring-loaded patterns is not essential in all helical and spiral gear-wheel pattern equipment, it can, however, prove of great value if the teeth are at a very difficult angle. An illustration of this type of pattern, together with a spray of castings, is seen in Fig. 6.33.

MODIFYING LOOSE PATTERNS FOR MACHINE MOULDING

The five-section pattern, seen on the left in Fig. 6.34, presents rather an intricate problem to the loose pattern moulder and, like many other similar types of patterns, involves a moulding technique which, to say the least, is both slow and tedious. However, demands for such castings in very limited quantities may suggest one explanation in favour of this type of pattern. Two other explanations

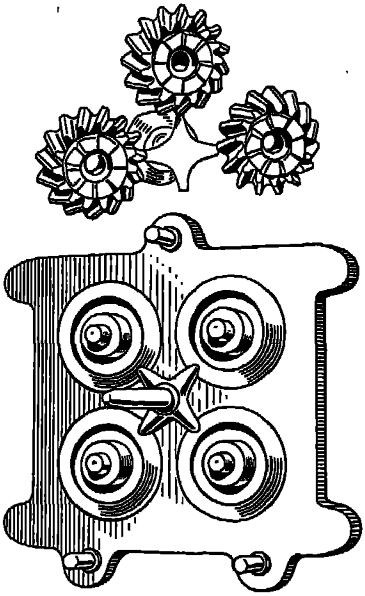


FIG. 6.33. *Gear wheels moulded as shown in Fig. 6.32, with spring-loaded twisting action on the pattern.*

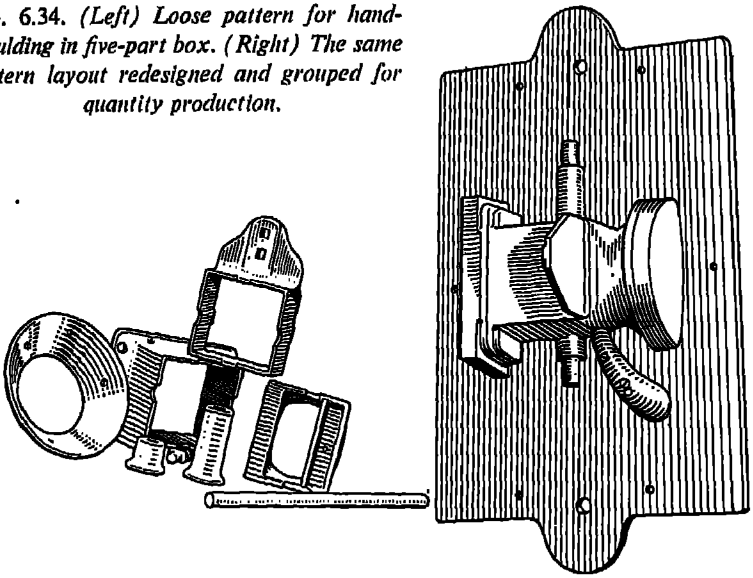


FIG. 6.34. *(Left) Loose pattern for hand-moulding in five-part box. (Right) The same pattern layout redesigned and grouped for quantity production.*

which also offer sound reasoning are the absence of moulding machines in any individual foundry or, what is more likely, lack of core-making and drying facilities. The two latter explanations have been put forward in view of a recent heavy demand for this same casting, which has necessitated modification of the pattern equipment in order to conform to machine moulding principles which, incidentally, involve an appreciable amount of coring. The modified pattern, seen on the right in Fig. 6.34, clearly illustrates the simplicity of such a pattern when compared with its five-section counterpart. This is especially so from the moulding standpoint and the distinct advantages such patterns present when considering accelerated production is often an important point.

HALF-PATTERNS FOR STRAIGHT-ARMED WHEELS

The application of this type of pattern is, of course, limited to either plate moulding or machine moulding, especially the latter, but in every case the exercise of extreme care in marking out and mounting is essential if the resulting casting is to be accurately matched at the joint line. The advantage of this type of pattern is obviously the economy in the initial cost of patternmaking, but, as previously stated, this only applies to wheels with straight arms which are designed to radiate equally from the centre of the pattern. The fitting of permanent down runners or ingates to such patterns does, of necessity, require careful consideration, as, obviously, that impression would occur in the drag mould if provision were not made for their simple removal for the moulding of the drag mould. When such

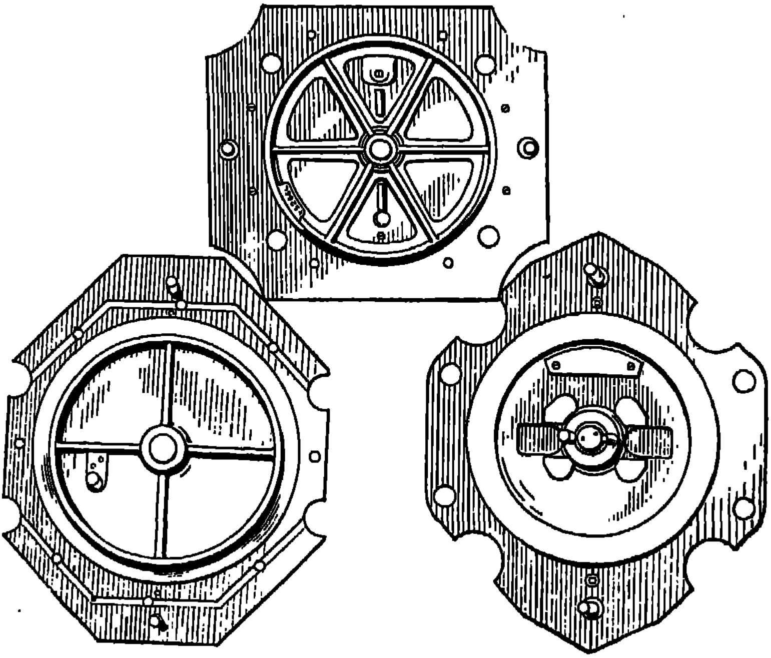


FIG. 6.35. *Group of wheel patterns. In each case the half-pattern is used for the cope and drag half of the mould, while the down-runners and ingates are detachable.*

castings are poured through down runners on the boss, the runner pins can be either screwed into the pattern or held in an upright position by a good fitting dowel pin of reasonable length, the dowel pin being turned a smaller diameter than the actual runner. Where the employment of an ingate on the joint is necessary, the ingate and down runner pin can be constructed as one unit and fitted to the pattern plate by two screws, preferably from the underside of the plates. By this means the reproduction of objectionable screw marks and the loose particles of sand which usually occur around the head is eliminated. Fig. 6.35 illustrates a group of such patterns, each of which is fitted with differing ingates.

HEAVY PATTERN EQUIPMENT

A combined check and gear box for a machine tool is shown in Fig. 6.36. It measures approximately 10 ft. 3½ in. × 4 ft. 10 in. × $\frac{13}{16}$ in. thick. As will be seen, there is a series of large rounds merging into flat surfaces. This, of course, means a weak pattern, or the alternative of adding prints and coring the rounded edges. The illustration will show that coring was the method decided upon. In making the plate which is $\frac{13}{16}$ in.

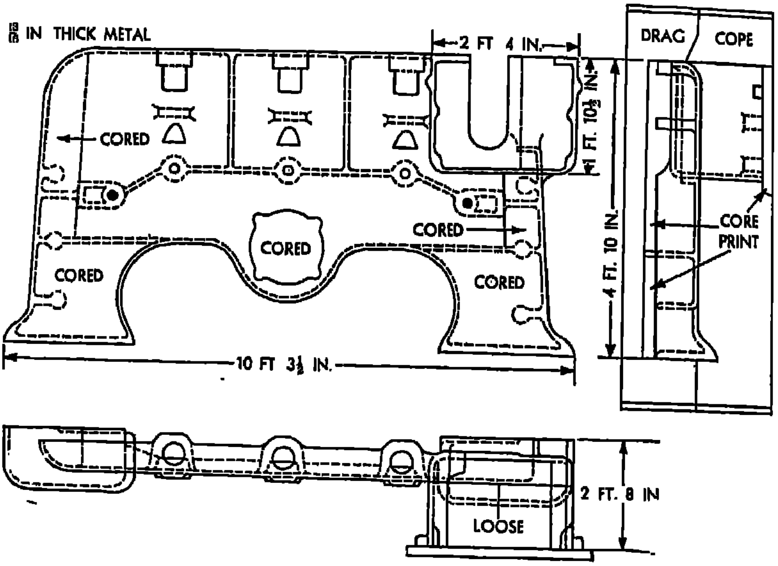


FIG. 6.36. *Pattern layout of a combined check and gearbox for a two-part mould.*

thick, the timber was run horizontally, and the joints left open ⅛ in. and each board pinned with steel pins. By this method of construction it is possible to guard against the ramming in of one section and also help to prevent growth due to timber swelling when in contact with damp sand.

Plenty of taper is allowed on all facings, and the gear box section is worked loose from the point indicated in Fig. 6.36. It is pinned to main frame with metal pins and sockets, an overhanging print is added to support the gear box core. The pattern is laid on a turnover board and the drag rammed. When turned over, and the partings made to ensure nice rounds, the cope box is added. This box part is of special design, the top bars which would normally be in the way of the gear box being left out, and a square formed. As the top of the overhanging print is level with the top of the cope box, location is perfect when closing.

MACHINE-TOOL BED

Fig. 6.37 shows the outline of a machine-tool bed. In Fig. 6.38 the mould is partly closed with the finished casting. The pattern is made to leave its own core with the exception of the U-shaped section of the tie bars. Projecting slides and facings are made loose, and are screwed or dowelled in position so that they can be slackened during the process of ramming. All pieces working loose are distinctly

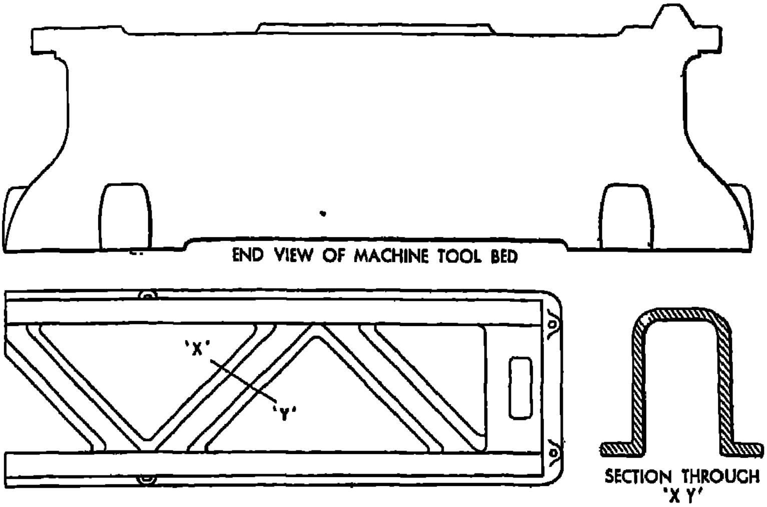
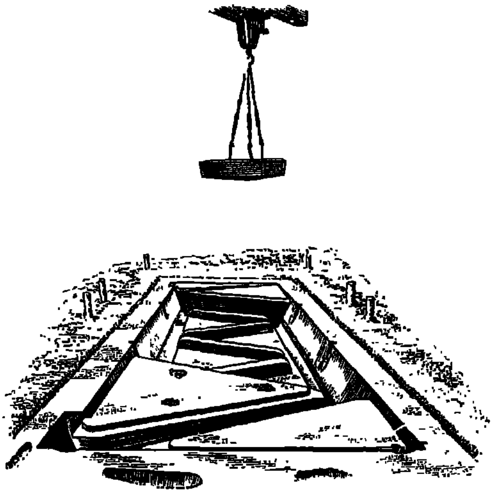


FIG. 6.37. *Outline of a casting for a machine-tool bed.* (Below) FIG. 6.38. *The mould for the machine-tool bed, shown partly closed.*



typed and, where possible, dovetailed on to the pattern to prevent mistakes being made through facings being placed out of position. The loose pieces are made in duplicate in all the larger standard patterns, since it has been found that by moulding and drawing the pattern the second set of facings can be fixed in position, and the second mould proceeded with while the first one is being finished, this sequence being continued till the finish of the order. The question of camber is one that arises in castings of this length. Short, straight battens of timber about 3 in. square section are placed in the moulding pit. A master straight-edge is used, and the short, straight battens adjusted to give the full camber at the centre, *in this case ⅞ in.*, gradually bearing in towards either end in the form of a curve. The sand

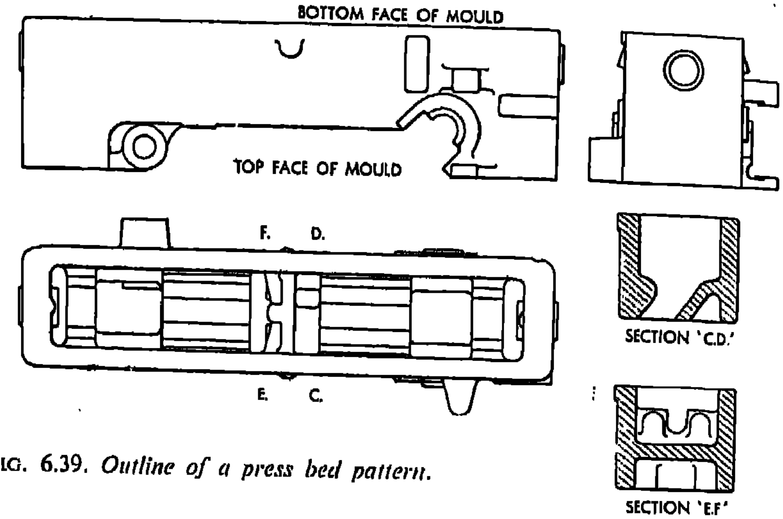


FIG. 6.39. *Outline of a press bed pattern.*

is rammed between them and the bed struck off at their level. The short battens are then removed, and the holes rammed up. The pattern is placed in the pit on the cambered bed and weighted, and is held in this position until completely rammed up.

PAINTING OF PATTERNS

This is a protective process of patternmaking that is very often given little consideration, but unless it is carried out properly it is far better to leave the pattern white. Cheap quality or badly mixed varnish, if used, will result in a bad draw in the foundry. There are various makers of first-class pattern varnish, and most firms have a colour scheme of their own. For instance, it is customary to paint unmachined parts yellow, prints black, and machined parts red. This is, then, a good guide to the moulder to show him where tooling is required, and thus he can make arrangements to keep those parts as clean as possible.

ALUMINIUM PRESSURE-CAST PLATES

To complete this survey of patternmaking, some mention must be made of two important recent developments: the use of pressure-cast patterns made from aluminium, and the use of epoxy resins for plastic pattern plates.

Pattern plates made by casting aluminium under pressure into dried plaster moulds are called pressure-cast plates. They can be double-sided matchplates, single-sided cope-and-drag plates, or composite plates which are single-sided plates from which both half-moulds are made (Figs. 6.40

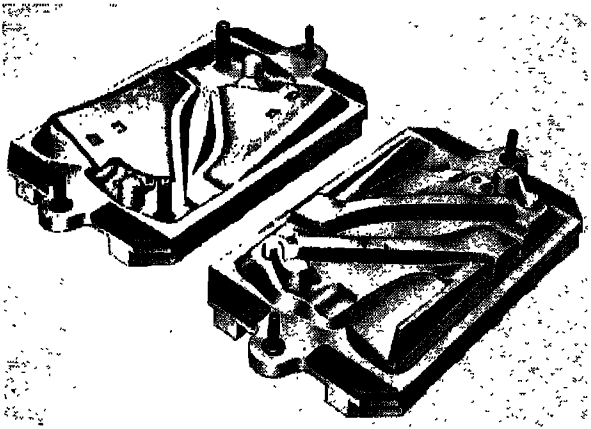


FIG. 6.40. *Pressure-cast aluminium cope and drag plates.*

and 6.41). Pressure-cast plates are advantageous when the moulding joint is irregular; multi-impression plates can be made from one master pattern, all pattern impressions being the same with sharp definition due to the pressure on the metal. Runner and feeder systems can be cast integrally with the plates and, owing to the very good surface finish after casting, the cleaning time is minimized. The cost of this type of equipment is much lower than that of machined pattern equipment and plates can be made quickly. Both the double-sided matchplate and the cope-and-drag plate can be used with snap flasks, slip flasks, pop-off flasks, steel moulding boxes or boxless moulding machines, and the cope-and-drag plate can be used on all types of moulding machine. Also, pressure-cast plates can be used for shell-moulding.

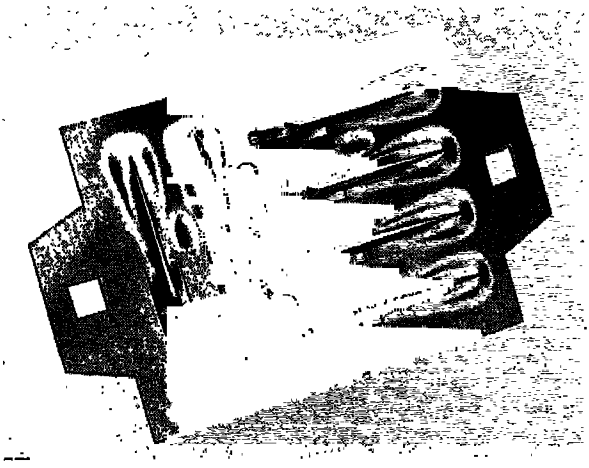


FIG. 6.41. *Double-sided pressure-cast plate from which castings are produced for a mower prong.*

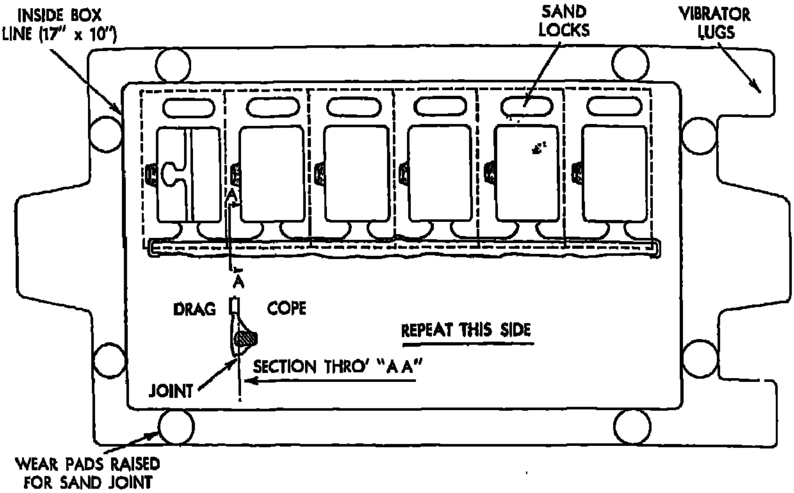


FIG. 6.42. *Typical matchplate layout (12 impressions).*

Method of Manufacture. An accurate master pattern in wood or metal is required and this must be smoothly finished with allowance for final and plate contraction. Before starting it is necessary to determine the type of plate required, as well as the general design, position of patterns, jointing of pattern, relation of jointing to plate level, design of runner and feeder system and position of downgate. A layout must be made, showing a plan view of the plate and sections to make all points clear. It is also necessary to know the type of moulding machine, size of flask or moulding box and its pin centres.

For snap-flask work, sand locks are cast on matchplates. These are raised areas on one side of the plate and matching recessed areas on the other, in order to stop cross jointing when the snap flask is removed. The layout should also show the point of the pattern joint which will be level with the moulding-box joint (in the case of a contour joint), and details of the shape of the plate, the depth of the ribbing and the bolting-down bosses to suit the type of machine on which the plate will be used. The general requirements for satisfactory plates are good moulding frames (preferably in cast iron for minimum expansion or heating during drying), accurate control of plaster mixing, drying of moulds and metal melting apart from the usual care required for pattern production in the final checking, and in the case of cope-and-drag and turnover plates, in the setting up and drilling of the pin holes. The accuracy of these are the ultimate requirement for a perfect match.

FIG. 6.43. *Metal registration dowel.*

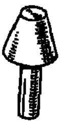
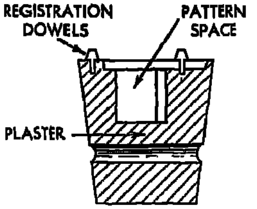


FIG. 6.44. *Tapered and grooved plaster block.*



Mould Making. If the layout of a simple pattern plate (Fig. 6.42) is studied, particular attention being paid to the general arrangement in the moulding box and runner system, it will be seen that dotted lines have been superimposed over the half layout. These lines represent the areas of plaster blocks to be made. From this stage the sequence of making a mould is: a former, an oddside, a set of blocks, assembly of blocks, cutting of runners etc. and drying. The depth of the former, the oddside and the block will all be the same as the moulding frame used for final assembly and casting. The pattern is moulded in metal casting plaster (gypsum and asbestos), making first a former to produce the joint, then a plaster oddside. From this, individual plaster moulds are made in two halves. If twelve pattern impressions are required in the finished plate, twelve separate plaster moulds are made, each comprising a top block and a bottom block of plaster, the total depth of each block being equal to the depth of the frames used in the process. These individual blocks are made in wooden frames. A parting medium is used between the top and bottom block of plaster, and compressed air is used to separate the blocks, which are located by metal dowels (see Fig. 6.43). The blocks are then trimmed to size on the outer edges so that when placed together the pattern impressions are in exactly the same relationship as on the layout. Each block is then tapered and grooved all round, as shown in Fig. 6.44.

A suitable moulding frame is filled with plaster and the blocks are placed face downwards together on this plaster base. It may be necessary to remove some of the base plaster to clear the pattern joint or cod joint. Another moulding frame is then placed on the base frame, the base-plaster surface is coated with a parting agent and the blocks are weighted to prevent them from moving or floating (Fig. 6.45).

The metal-casting plaster is then poured round the blocks, completely filling the frame. When nearly set, the weights are removed and the top of the mould is strickled flat. When set, the mould is lifted off and turned over, the plate outline is marked on this half mould with an indelible pencil and the top blocks, after being cut $\frac{1}{8}$ in. smaller in area than the bottom blocks, are tapered and grooved and each placed on their counterpart, the position of each block being governed by the metal dowels already cast in each pair of blocks. A second frame is now placed on top, pins are placed through the two frames, the blocks again weighted and this frame again filled with plaster. These frames then become a pair of moulds, the

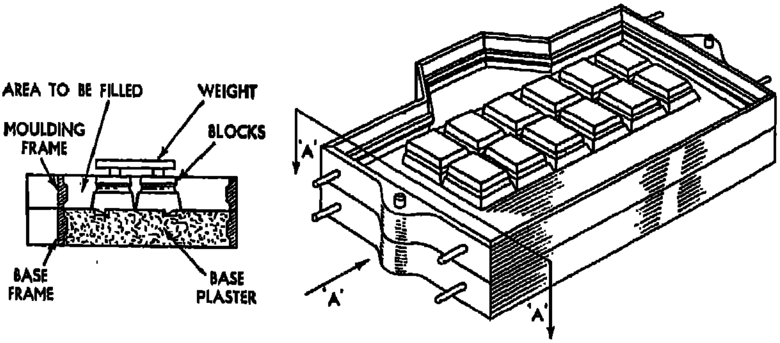


FIG. 6.45. *First half-mould assembled.*

match being governed by the two frame pins. When the pair of moulds are parted, the dowels are removed from the individual blocks and the holes filled with plaster. The runners are then marked as shown on the layout and are cut out by hand. The mould is cleaned and checked. In the case of a double-sided plate the downgate for the pressure casting is cut through the extra shape-area of the top side mould so as to correspond with the top plate and the reservoir of metal during casting. At this stage the mould is complete for a double-sided plate.

If the pressure-cast equipment is for cope-and-drag plates, the moulds are parted, each becoming a separate bottom mould on which is built up the necessary back ribbing and bosses. Another moulding frame is placed on top, complete with a pair of pins, and the moulding frame filled with metal-casting plaster. When this is set the moulds are parted and the ribbing and bosses, taken out, thus leaving the back shape required in this half mould. This process is repeated on the other mould so that there are now two pairs of moulds, i.e., one for the cope plate and one for the drag plate. The downgates for the pressure casting are then cut into the top mould of each pair, producing the back ribbed side of the plate.

Drying of Moulds. Before drying, small holes are pierced through each top mould from the high spots of the pattern space, to form venting during casting. The moulds are then stood on edge in a suitable drying stove, and the temperature is slowly raised over a period of four to six hours and held to about 400 deg. F. It is absolutely essential that both the free and combined moisture is entirely extracted, otherwise blowing will occur when the metal enters the mould cavity. This is because the mould permeability is very low compared with sand moulds; also, once metal has entered the vent holes they no longer function. There should be a good fan circulation of air around the oven, as a considerable amount of moisture is extracted in the form of steam. For example, a pair of frames measuring 28 × 19 ×

6 in. contains 112½ lb. of water, all of which has to be dried out. This is essentially a drying process, not a baking process.

Casting. Various aluminium alloys have been used, the most popular being L.M.4 and L.33. The moulds are cleaned and the bottom mould placed on a strong metal base plate; if double-sided, a spacing frame is then placed on the mould so as to give the required thickness of the finished plate. The top mould is then closed over and a well-ribbed, strong plate placed on top, of the same shape as the moulding frames. A hole through the V-shape of the front side is then lined with a loose plaster ring, a disk of asbestos 1/16 in. thick placed on this hole, and the metal reservoir, previously lined with plaster and dried, is bolted over the disk. The top plate is also bolted to the base plate, so holding the moulds tightly together. Metal is poured into the reservoir. The lid is clamped in position on top of the reservoir, to which is attached a compressed-air line. The compressed air is turned on to a low pressure (approximately 5 lb. per sq. in.), sufficient to break the diaphragm and allow the metal to enter the mould cavity. The air already in the cavity escapes through the vents and along grooves scratched on top of the mould to the side. Air pressure is maintained for a short time and the mould stripped after cooling from casting. It must be remembered that the plaster, being a semi-exothermic material, keeps the metal molten much longer than sand, the latter normally allowing the heat to escape more rapidly.

When cool, the plates are stripped, sawn to shape if necessary, polished, and straightened and drilled to suit the moulding box or snap flask, this being all that is necessary to complete a double-sided plate before taking off test castings. In drilling cope-and-drag plates the backs are first straightened and machined flat. They are then set up side by side and, with the left-hand plate rigid, the other is adjusted so that all the half patterns on one correspond exactly with their counterparts on the other. The pin centres are marked, and the plates are then turned on end, the routine being repeated. Holes are then carefully drilled and reamed to the centres marked and, if necessary, hardened steel bushes are inserted or pins fitted. Any extra fittings such as steel wear pads are then fitted and the plates are ready for test run-offs. In general, the method of manufacture of these plates is straightforward, but like all casting processes, pressure-casting has its own peculiar problems and consequently only experience can give consistently good results.

CAST EPOXY-RESIN PATTERNS

In the field of plastics materials one notable contribution has been the post-war development of epoxy or epoxide resins. They are useful to the patternmaker because before curing they are in liquid form and therefore can be cast by simple gravity-casting methods; the shrinkage on curing is negligible; and cure takes place at normal workshop temperature. These are the basic properties that make epoxy resins suitable for such work; it is also convenient that pattern equipment can be repaired or modified with the same material, that the patterns suffer no harm from the chemicals in CO_2-hardened sand, and that they are light in weight (one-half to two-thirds the weight of aluminium). The advantages claimed for this new medium are low cost, and speed allied to quality. Low cost arises from the large saving of labour in the finishing operations of cast metal patterns; quality is maintained because the cast resin will reproduce the master pattern in detail and shrinkage will vary from nil to only 0·0015 in. per inch.

The process of reproduction is fundamentally simple. A mould must be made from the master pattern. Plaster of paris gives ideal definition, but sand moulds—of hard-rammed clay-bearing sand or of CO_2-hardened sand—can be suitably sealed and lacquered with polyvinyl acetate or other coating. A release agent, of wax and/or polyvinyl alcohol, is applied to the mould surface to prevent the resin bonding to the mould.

The master can be reproduced as a split pattern or incorporated in a resin plate. Two techniques may be employed:

(1) The mould can simply be filled with resin-hardener-filler mixture to give a casting that will be hard in approximately 24 hours.

(2) For thin-sectioned work, for broken joint-line plates, or for double-sided plates, a "wet lay-up" technique may be necessary. In this method layers of resin and glasscloth are built up to give what is virtually a glass-fibre/resin laminate of high flexural and tensile strength. In the case of a double-sided plate the two surfaces are laid-up horizontally. When these have gelled the half-sections of the moulds are secured together and the middle section of the plate is poured vertically.

Epoxy resins are adhesives for metals, and metal inserts can therefore be incorporated if desired, e.g., bushes to take the pins of moulding boxes. The cured resin can be machined, drilled and tapped. Using either simple gravity-casting methods or resin/glasscloth lay-up procedure to suit each job, there is almost no type of pattern or core-box which cannot be reproduced. Even heavy pattern equipment might be duplicated by lay-up methods more cheaply than by replacement with wood. In modern foundry practice the new resin medium should take its place alongside existing materials, finding its greatest economy where high standards and intricacy of shape are most demanded.

Chapter 7

MOULDING SANDS AND DRESSINGS

SAND is the principal basic moulding material used by the foundryman, whether it is for iron, steel, non-ferrous or light-alloy castings. For every ton of iron castings produced it is estimated that one ton of sand is used. The study of foundry sands constitutes one of the main sections of foundry technology and sand testing has become an essential part of the day-to-day control of foundry operations. In the early years of the century foundrywork and the preparation of moulding and core-sand mixtures was still a craftsman's art. Particular sands were used because of custom or renown for a certain class of work, and the experienced moulder, often a highly skilful craftsman, could produce results with his limited equipment which were equal to those of the best modern sand plant, based on his long experience and rule-of-thumb methods. His mixtures were a closely guarded secret, and endless varieties of such mixtures were in use.

During the past 20 years considerable changes have taken place in methods, equipment and the materials used. One of the most far-reaching changes has been the progressive growth of mechanization, principally the introduction of the centralized sand plant which feeds sand by conveyor belt to the moulding units via overhead storage bins and hoppers, and returns used sand continuously back to this plant for re-bonding, tempering, remilling and aerating, ready for use again. By reducing the number of sand mixtures to a minimum, preparation of moulding and core sand has been very much simplified. In a modern mass-production foundry, a unit sand may be circulated once every hour through the system and the sand plant may include means for automatically controlling the moisture content, bond addition and sand temperature. The control of sand preparation and maintenance of predetermined limits of moisture, bond, permeability and other properties play an important part in ensuring good moulds and a minimum of work in the fettling shop, with maximum output of good castings. As a result of our growing knowledge of the nature and properties of foundry sands, not only are we able to make the best use of our natural resources of sands suitable for moulding and coremaking, but also to produce synthetically sands having the desired combination of properties for particular types of foundry work.

DEFINITIONS

The general term "sand" covers a wide range of granular minerals, including, in addition to moulding sands, sands used for furnace lining; silica sands used in the glass industry, and to an increasing extent in foundries for synthetic sand mixtures and as core sand; building sands; sand used as abrasives and filtering mediums; and sands for numerous minor purposes.

The following definitions of some foundry terms which are used in the text are included for the benefit of readers who are not familiar with their precise meaning.

Green Sand. Sand in the green, or undried, condition. Casting into green sand or undried moulds is common practice for the majority of small- and medium-sized ferrous and non-ferrous castings.

Dry Sand. Sand from which all the free, or uncombined, moisture has been removed, usually by heating in a drying oven or stove. Dry sand practice is used mainly for the production of larger castings, or where dimensional accuracy and soundness are particularly important. The sand mould may be completely dried before the metal is poured into it, or "skin dry," to a depth determined by experience as safe for casting into.

Facing Sand. The sand which is used against the face of the pattern and which forms the face of the mould. It is usually a mixture of old sand (floor sand) and new moulding sand, or other bonding materials, and is prepared for use by first tempering with the right amount of water. It is then milled and riddled to produce a sand of fine texture and suitable bond, which will give a smooth, firm impression of the pattern against which it is rammed, and will not wash or crumble away when molten metal enters the mould.

Backing or Floor Sand. The accumulation of moulding sand from cast-up moulds which is used over and over again as the basis of the facing sand and to fill in the mould at the back of the facing layer.

In most modern mechanized foundries the whole of the sand in the moulding system is circulated through the sand preparation plant, where necessary additions of bonding clay, new sand, coal dust and so on are made, and there is no separate facing sand, merely a system or unit sand as it is called.

Black Sand is the term sometimes used to describe foundry moulding sand or floor sand, particularly in the iron foundry where, because of additions of coal dust to the sand, and the action of hot metal, every particle soon becomes coated with a black carbonaceous film, and the sand contains a considerable proportion of fine coal and coke particles.

Synthetic Sand usually refers to moulding sand prepared artificially from sharp, or unbonded, silica sand by the addition of suitable bonding

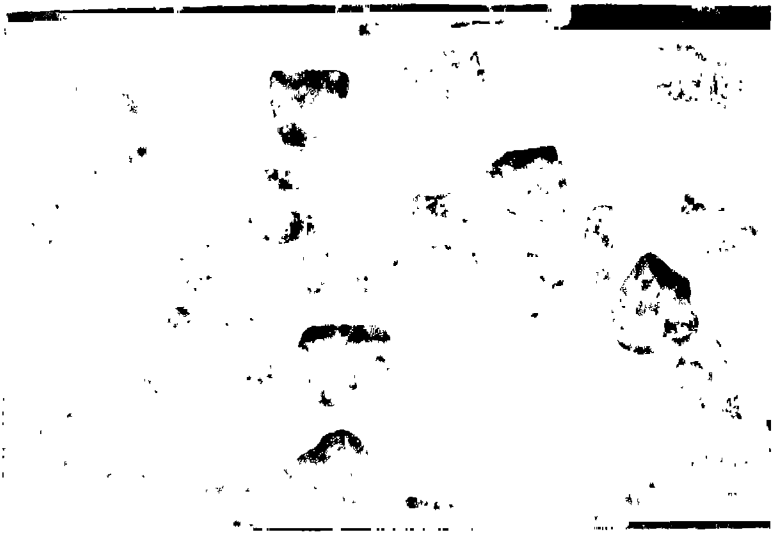


FIG. 7.1. *Photomicrograph of Southport sea sand, which is used extensively in the Midlands and the North as a core sand. When a fine surface and good green bond are required, it is usual to add from 10 to 15 per cent of red moulding sand, such as the Bromsgrove variety.*

clays. Synthetic moulding sand mixtures may, and often do, contain a proportion of naturally bonded sand. The term in its general sense will also include silica sand mixtures bonded with cement or any of the organic materials, such as oils and cereal binders usually classed under the heading of core binders.

Naturally-bonded Sand. Sand which contains "as quarried" a proportion of associated clay minerals. After milling, and with a suitable percentage of moisture, such sand has the bond required for moulding.

Core Sand. Sand used for making cores to produce hollow castings. Usually high silica content sands (generally described as "silica sand") with worn rounded grains of regular size and shape, such as sea, river, lake, or desert sands are used with special core binders. Ordinary moulding sand is also used for coremaking to some considerable extent.

Oil-sand. A common name for a silica sand bonded with an organic binder, frequently containing a proportion of linseed oil or other drying oils mainly used for coremaking (Figs. 7.1 and 7.2).

NATURE AND CLASSIFICATION OF SANDS

Foundry sands in general are composed of grains of quartz or

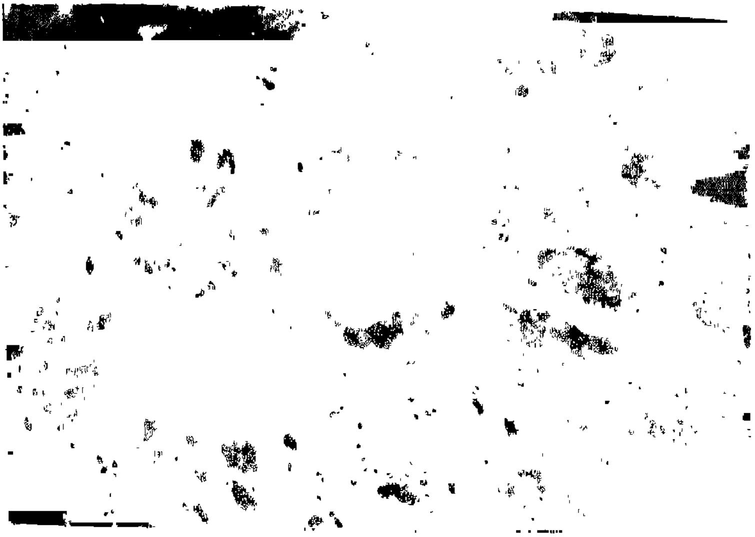


FIG. 7.2. *Part of a baked oil-sand core under the microscope. Note the irregular packing of the quartz grains and the cementing film of dried oil at the points of contact. The sand shown is ordinarily Southport sea sand bonded with 2 per cent of core oil.*

quartzite, crystalline forms of silica, which are found associated with some form of clay. In addition, there are frequently small amounts of other minerals present, such as felspar, the character of which depends on the nature of the rock from which the sand originated. Those sands containing suitable bonding clay comprise the natural moulding sands, whilst the clay-free sands usually termed sharp or silica sands, are the basis of synthetic moulding sands, oil sands and shell moulding sands used in the foundry for moulding and coremaking. The colour of sands varies from pure white to deep red or brown, according to the impurities present, particularly iron-bearing minerals.

The multitude of small particles making up a sand deposit is produced by the disintegration of massive rocks by natural forces of heat and frost, wind and water action, and general weathering. The particles are frequently carried considerable distances by flowing water before being deposited on river-banks, the beds of lakes, or in the sea. Whilst recently deposited sand may be found at the surface, many of the older deposits in course of time have become buried to considerable depths by more recent deposits or changes in the land formation.

Such sand beds, as they are called, are often of considerable extent and thickness, but owing to the natural classifying action of flowing water, such deposits usually vary progressively in size of grain and clay content from top to bottom or end to end. It is, therefore, usual to grade the sand from particular parts of large deposits according to fineness or clay content, in order to supply a reasonably uniform material to suit particular purposes. For example, Erith moulding sand is available in several grades from mild to extra strong, and there is fine, medium and coarse Mansfield red moulding sand produced from different parts of the same sand bed.

The principal types of sand deposits are usually classified (A) according to the chief agent in deposition or formation as follows:

(1) Wind-blown or Aeolian,
(2) River or Fluvalite,
(3) Lake or Lacustral,
(4) River mouth or Estuarine,
(5) Sea beach or Marine,
(6) Glacial and residual;

or (B), according to the geological age or rock system in which the sand deposit occurs (see *Sands and Crushed Rocks*, by A. B. Searle). Thus the sand may originate from primary or igneous rocks, from secondary deposits or from tertiary and more recent strata, all of which are subdivided into a number of geological systems.

In the British Isles sands are found in most parts of the country, but the main sources of moulding sands are the Bunter sandstone, or Lower Trias of the Triassic system, the upper and the lower green-sand beds of the Cretaceous system, and the Eocene series of tertiary deposits which include most of the Southern England sand beds.

COMPOSITION OF SANDS

As already stated, the chief constituent of foundry sands is quartz (silica). Other minerals present are usually compounds of silica with alumina, and complex silicates containing lime, magnesia, oxides of iron, and the alkaline earths, soda and potash, in varying proportions. These substances making up a sand can conveniently be divided into three groups:

(*a*) *Quartz*, constituting the bulk of the actual sand grains;

(*b*) *Clay substance*, which forms the bonding medium around the quartz grains;

(*c*) *Felspar, mica, or other fluxing substances*, which are not desirable in a refractory material but are usually present in varying proportions in most sand deposits.

The chemical analysis of a number of typical British moulding sands is given in Table 7.1. The usual limits of composition for moulding sands

TABLE 7.1
CHEMICAL COMPOSITION OF TYPICAL BRITISH MOULDING SANDS

Type of sand	*Silica* SiO_2	*Alumina* Al_2O_3	*Oxides of iron* FeO Fe_2O_3	*Titanium oxide* TiO_2	*Calcium oxide* CaO	*Magnesium oxide* MgO	*Alkalis* Na_2O K_2O	*Loss on ignition*
Erith loam, mild	90·5	3·94	2·16	0·23	0·20	0·31	1·70	0·95
Mansfield red	82·5	4·96	1·27	0·17	2·39	1·56	2·30	2·15
Belfast red	81·5	8·84	1·84	0·35	0·86	0·81	4·37	2·24
Birmingham red	84·9	6·69	1·43	0·40	0·29	0·43	3·81	1·76
Erith loam, strong	83·8	6·92	2·91	0·43	0·52	0·83	2·63	1·95
Scottish rotten rock	81·4	5·74	2·02	0·12	2·82	0·61	2·73	5·0
Ormskirk bunter red	92·4	3·94	0·50	0·19	0·12	0·16	2·17	0·9

From paper : "Sands and Sand Testing," by Dr. J. G. Skeel, F.T.J., 1931.

are: silica 80 to 90 per cent, alkali trace to 3 per cent, alumina (as clay, etc.) 4 to 9 per cent, lime and magnesia trace to 3 per cent, and iron oxides 1 to 4 per cent. N.B. *The lower the percentage of alkali and lime or magnesia, the better the refractoriness.* Whilst the chemical composition of sand gives a valuable guide to its refractory character, the primary factors in determining the working properties of a sand are: (1) the shape, size, distribution and surface character of the grains; (2) the amount and type of clay; (3) the moisture content.

Sand grains are of varying character as regards shape and surface condition which can be conveniently examined under a low-power lens or binocular microscope. Some grains have a roughened or pitted surface which affords a better grip for bonding films of moist clay than the perfectly smooth polished surface of wind-blown sand. Whilst some grains are well rounded and worn, others will be found with sharp, angular fractured surfaces just as produced by pounding a hard rock into fragments, and some sands contain numbers of small masses of grains cemented together into compound grains (see Figs. 7.3–7). An interesting study and classification of sand grains, with many excellent illustrations, appeared in the *A.F.S. Transactions*, 1931: H. Ries and G. D. Conant, *The Character of Sand Grains.*

To identify the true character of the grains of a bonded sand, the clay substance and any fine mineral matter should first be removed. This may conveniently be accomplished by boiling a small quantity of the sand for a few minutes with a dilute alkali such as caustic soda or ammonia.

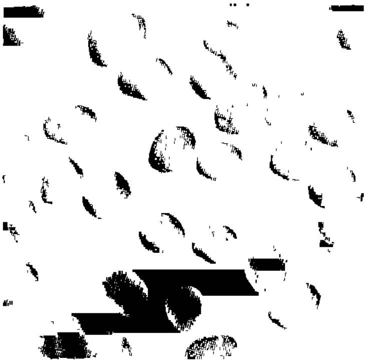


FIG. 7.3. *Round quartz grains with worn surfaces.*

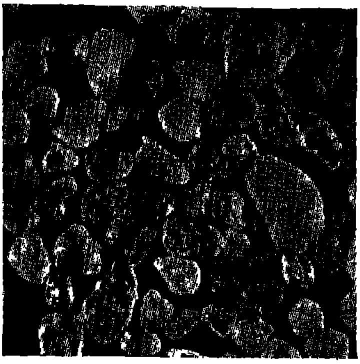


FIG. 7.4. *Sub-angular grains of clean silica sand.*

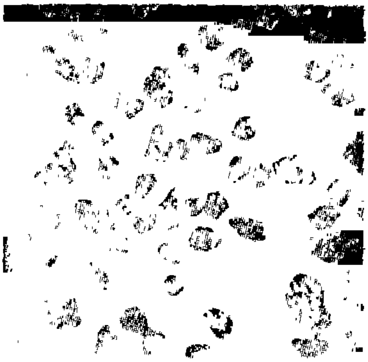


FIG. 7.5. *Typical angular and sub-angular quartz grains.*

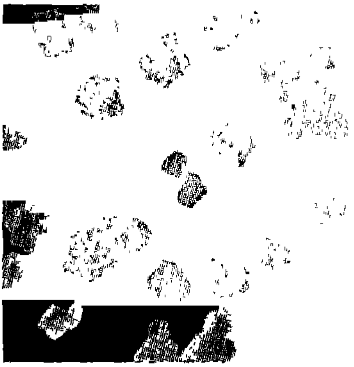


FIG. 7.6. *Compound sand grains cemented by silica and dark iron oxide.*

The sample is then diluted with water in a tall beaker or test tube, shaken up and the sand grains allowed to settle to the bottom before pouring off the suspended clay matter (see *Recommended Methods of Sand Testing*, I.B.F.). By repeating the washings a few times, then draining and drying over a hot plate, the clay-free sand grains are available for examination. In the case of grains with a coating of iron oxide or other staining, a wash with warm dilute hydrochloric acid will leave the quartz perfectly clear and break down most of the cemented groups of grains, revealing the true shape and surface character.

The shape and size of sand grains has an important bearing on the packing together of a mass of grains (J. J. Sheehan, *Proceedings I.B.F.*, 1938-39, "Core-shop Control"), and in consequence on the pore space and

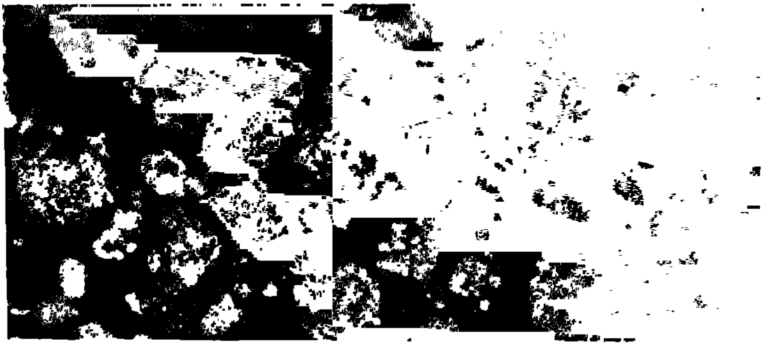


FIG. 7.7. *Typical clay-bonded moulding sand as seen under a low-power microscope. The clay forms the bonding medium around the quartz grains.*

permeability of the mass, as well as on the flowability and deformation value of the sand. This will be discussed later. Angular grains give greater mechanical strength than round grains for the same amount of bonding clay, so that where maximum strength or bond is required, a subangular, or angular, type of grain, preferably with a roughened surface coated with a thin, tenacious film of bonding matter, is an advantage. Rounded grains give maximum flowability with high permeability, and are of advantage for ease of ramming, and particularly in mechanized core production. Owing to the close packing of uniformly shaped grains, such sands are prone to troubles such as surface cracks and scabs on the mould face arising from expansion of the quartz grains when heated.

The size of grain, or grading, is measured by sieving a known weight of sand on a series of test sieves and the individual weights of grains on the various sizes of sieve may conveniently be set out in graphical form to give a picture of the mechanical composition of the sand. Such curves as those shown in Fig. 7.8 are obtained by plotting the cumulative weight percentages against the sieve apertures, thus bringing out contrasts and similarities with other sands at a glance. The sand grains in natural bonded moulding sands are seldom

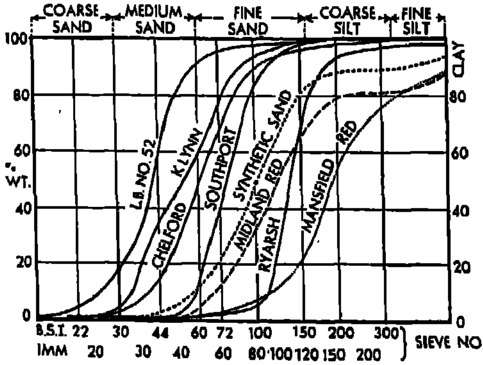


FIG. 7.8. *Gradings and classification of sands.*

as smooth or rounded as the sharp sea, river, or desert sands; whilst their grading is more varied. Many of the silica sands used in the foundry for core sand mixtures have very uniformly sized grains, and it is common to find 97 to 99 per cent of grains between 0·10 to 0·30 mm. diameter (see Figs. 7.3 and 7.4).

BONDING CONSTITUENTS

The term "clay" is applied to a particular group of minerals which vary from the pure white china clay or kaolin to the hard, black, shale-like refractory fireclays, in which the chief constituent is hydrated silicate of alumina. The term may be misleading when considering the clay substance or bond of a naturally bonded sand. Research into the chemical and physical character of clays has shown that both composition and structure have great influence on their working properties. The distinctive property of clay is its plasticity, which is imparted to a mass of sand in the presence of moisture. Moisture in a moulding sand is as essential as the clay substance itself, and exists in two ways: (1) as free moisture which can be removed by drying at 110 deg. C., and (2) as combined or absorbed moisture in the clay particles which is only removed by heating to a considerably higher temperature, which varies according to the particular class of clay.

When moist clay loses its free moisture it becomes a hard mass, losing all plasticity, but regaining it when retempered. When, however, the clay is heated sufficiently to lose its combined water, it becomes dead and does not regain its plasticity by the addition of water. This is, of course, what happens to the sand layer at the face of a mould when cast, the heat driving out all moisture from the clay bond and decomposing any organic matter or carbonaceous matter in the sand. Fortunately, owing to the low thermal conductivity of a sand mould, the influence of the molten metal in destroying the bond is restricted to a fairly shallow depth, depending on the size and section of the casting.

We now know that clays with the smallest particle size and highest moisture absorption properties give the highest bond strength or adhesion to a mass of sand grains (Dr. G. H. Piper, *I.B.F. Proceedings*, 1938, "Bonding Clays and Properties of Synthetic Moulding Sands"), whilst the life of the bond, i.e. the ease with which it loses its combined water and becomes dead bond, varies with composition and structure.

At very high temperatures clays soften and undergo physical and chemical changes forming glassy fused bodies. The softening temperature of clays varies according to type and purity, and in most natural moulding sands varies from 1,250 to 1,400 deg. C. (Dr. Skerl, *I.B.F. Proceedings*, 1931, "Sand Testing." See also Table 7.2). As this is considerably below the

TABLE 7.2 CHEMICAL COMPOSITION OF BONDING CLAYS

Type of clay	*Silica* SiO_2	*Alumina* Al_2O_3	*Iron oxide* Fe_2O_3	*Calcium oxide* CaO	*Magnesium oxide* MgO	*Titanium oxide* TiO_2	*Alkalis* $K_2O + Na_2O$	*Loss on ignition per cent*	*Fusion temperature deg. C.*
Bentonite	61·5	22·1	4·2	1·74	2·27	0·22	1·56	5·8	1,330
Colbond	60·4	19·2	3·31	1·59	1·01	0·97	0·70	10·4	1,490
English ball clay	48·7	34·8	1·37	0·47	0·22	1·05	1·64	11·7	above 1,450
Stourbridge black fireclay	45·1	33·4	2·50	1·20	0·94	1·55	0·83	14·6	above 1,500
China clay	55·9	29·6	1·25	1·10	0·61	1·50	1·80	9·1	above 1,500
Clay from Midland red moulding sand	53·7	25·4	6·94	0·34	2·06	0·62	3·12	7·8	1,390

From Paper: "Bonding Clays and Properties of Synthetic Moulding Sands," by G. H. Piper. Proc. I.B.F. 1938-39.

TABLE 7.3 NATURAL BONDED SAND MIXTURES USED IN MIDLANDS FOR CAST IRON—GREEN-SAND MOULDING

Type of sand	*Proportion of new sand used* *Per cent*	*Class of work*	*Moisture per cent*	*Green compression str. lb. per sq. in.*	*Green permeability A.F.S. No.*	*Dry compression str. lb. per sq. in.*
Mansfield red	8–9	General engineering	6·0	3·1	25	41·5
Bromsgrove red	unit sand 1 per cent 0·2 C.D.	Small electrical fittings	6·0	5·2	30–40	80–85
Midland red	25 3 C.D.	General engineering	5·5	7·1	23·3	73
Wombourne red	10 5 C.D.	Medium weight valves	5·5	5·0	38–40	—
Bromsgrove red	17 3 C.D.	Small castings high duty iron	5·5	2·7	41	40
Stourbridge red*	35 6 C.D.	General engineering up to 10 cwts	6·8	5·3	16–18	121
Wombourne red	33 6 C.D.	Stove plate for enamelling	2–4·5	4·6	22	—
Harborne red*	33 8 C.D.	Machine tools, small and medium weight	6·7	5·0	26–30	94

*Hand moulding.

softening point of quartz, the refractoriness of the sand, as a whole, is really determined by that of the bonding clay and in synthetic sand mixtures we find high-refractory fireclays used in certain instances where the mould is subjected to very high temperature.

Apart from the clay substance associated with naturally bonded sands, clays of interest in foundry practice may be divided into six classes:

(1) *Kaolinite* (or china clay) which includes many types of siliceous clay and refractory clays in general of low plasticity. China clay corresponds to the formula $Al_2O_3.2SiO_2.2H_2O$, and is found in Devon and Cornwall. It is used largely for pottery making and in many chemical industries, including paper manufacture. It is freed from coarse particles by sedimentation at the mines, the bulk of the particles being below 10 microns diameter (1 micron = 0·001 mm.). Owing to its refractoriness, the softening point is over 1,700 deg. C. It is often used as a bonding ingredient in mould and core washes and helps to maintain coarser particles in suspension. Because of its relatively slight bonding power, or plasticity, china clay is not generally suitable as a synthetic bond for moulding sand. The general kaolinite group also includes ball clays and fireclays, dealt with under classes 2 and 3.

(2) *Ball Clays.* These are a special class of plastic refractory clay which occur to a very limited extent in Britain (Devon blue ball clay), and have been used for synthetic sand mixtures in the U.S.A. The purest and best types are expensive and are used in the manufacture of retorts, crucibles, and the like, where refractoriness combined with high strength and plasticity is required.

(3) *Fireclays.* These are refractory clays and are used particularly in most types of furnace construction for brick-making, crucibles, and to a limited extent as additions to moulding sand for steel founding. More recently they have been used in synthetic sand mixtures, together with bentonite. Some of the best fireclays are found in seams associated with coal measures, as in Staffordshire, and the hard, black, shale-like lumps are usually weathered before being milled for use. Such clays contain a considerable amount of organic matter and combined water. Fireclays include various types of siliceous clays, flint clays and materials with softening points ranging from 1,600 to 1,700 deg. C. or over. The particle size varies widely, up to 20 microns diameter, as does the plasticity. In the U.S.A. it is used to a considerable extent with other colloidal clays, such as bentonites, for synthetic moulding sand. It is said to be more durable and cheaper than bentonite clays alone (S. E. Ash and E. O. Lissell, *Foundry Trade Journal*, Aug., 1941, "Fundamental Aspects of Foundry Sands").

(4) *Bentonites*. These are colloidal clays of extremely small particle size which have remarkable water absorption properties. The principal known deposits are in North America and Canada, though they are also known to exist in New Zealand, South America, and North Africa. Bentonite, the chief mineral constituent of which is montmorillonite (formula $Al_2O_3 4SiO_2 xH_2O$) is found in beds several feet thick, and is dried and pulverized for use to appear as a soft, creamy white or greyish powder in commercial form. There are two main types in use in America, the western and southern bentonites, both of which are used extensively for bonding foundry sand. Although of similar composition, the western bentonites swell far more than the southern type when mixed with water. To give some idea of the swelling and moisture absorption properties of western or Wyoming bentonite, the type which has been used mostly in Great Britain, a paste of 10 per cent bentonite and 90 per cent water will just flow through a ½-in. pipe under its own weight. The particle size of bentonite clay is smaller than any other type of plastic clay, a large proportion being less than 1 micron in diameter, and the western bentonite has by far the highest bonding value of any known clay at normal temperatures. The refractoriness of bentonite is only fairly good. Its fusion point is in the region of 1,350 deg. C., and in the same range as the clay bond of natural moulding sands.

(5) *Limonite and Illite Clays*. These types of mineral often occur as a constituent of the natural clay substance of moulding sands. Limonite, or hydrated iron oxide, often occurs as a tenacious coating on the surface of quartz grains giving the sand a yellow, or brown, colour, whilst iron in the form of anhydrous oxide (hematite) accounts for the bright colour of the famous red moulding sands of the Mansfield, Belfast, and Birmingham districts. Both ferrous and ferric oxides may be present in such sands, and ferrous oxide is a dangerous constituent, as it readily forms fusible silicates at high temperatures. For this reason, and because this type of clay substance usually contains sodium and potassium minerals which also form readily fusible silicates, the refractoriness of these fine-grained and brown moulding sands is not particularly high, and they are seldom used with the higher melting point metals such as steel. They are, however, used very largely for medium and light iron castings and for non-ferrous alloys.

The bonding properties of this class of clay vary according to the nature and quantity of the associated minerals, although, in general, it has higher strength than the kaolinite group, but considerably lower than the bentonites. The durability, or life, of bond is lower than most other types, but these sands have good working qualities and a fairly high moisture absorption.

(6) *Fuller's Earth.* Soft, earthy varieties of clay with little or no natural plasticity have recently been developed as home-produced alternatives to bentonite in synthetic moulding sand practice in Britain. They vary from greenish-grey to yellow and brown in colour, and occur fairly extensively in the lower green sand and Jurassic strata of Britain, and are mined in Devon and Dorset. The prepared fuller's earth "Fulbond" is available in several grades, e.g. No. 1 with a narrow mouldable range, No. 2 with dry strength and plasticity, and No. 4A with a wide mouldable range and rapid bond development. As a natural development of the study of bonding minerals and their influence on the properties of moulding materials, the use of combinations of two or more types of clay is becoming more prevalent in synthetic sand mixtures in order to obtain the desired combination of properties.

MOISTURE CONTENT OF SANDS

Without moisture, moulding sand becomes a dry, powdery mass owing to the loss of plasticity and bond of the clay substance. As the proportion of water is varied, the working properties of a sand also vary, and for any particular sand mixture there is a particular moisture content or range at which the green bond and toughness reaches a maximum. The curves shown in Fig. 7.9 illustrate the variation in properties of a typical moulding sand as its moisture content alters. The properties of green and dry strength, flowability and so on, and their relation to the amount of moisture present are governed mainly by the type and quantity of clay bond present as already described in the last section (J. Dearden, *I.B.F. Proceedings*, 1938-39, "Influence of Moisture on Properties of Sands"), and since maximum values for these various properties usually occur at different moisture figures, the choice of moisture content at which to work will depend upon such factors as the type of moulding equipment and class of casting being made, as well as general foundry conditions. It is often a compromise between a sand condition which is easy working or flowing and yet

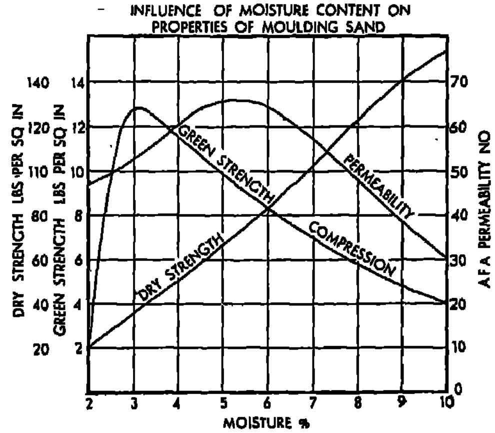


FIG. 7.9. *Effect of moisture content on properties of moulding sand.*

has sufficient strength to stand stripping from the pattern after ramming. Owing to the constant loss of moisture from moulding sand in the foundry under the heating action of hot metal, and by drying action of the air, regular retempering of the sand is necessary in order to maintain anything like uniform working properties, and good moisture control is one of the most important single factors in obtaining consistently good moulds. In most modern sand preparation plants a visual reading meter is now fitted in the water supply line, so that the operator can measure exactly the volume of water put into a batch of sand, and frequent moisture tests should be taken of the sand reaching the moulder in order to compensate for any variations in moisture loss throughout the day. Electrically operated meters are also available for continuous sand plants which can be used for either hand or automatic control.

In general it can be stated that low moisture content gives low dry strength, with possibility of sand washes and dirt inclusions in the casting. In green sand moulding particularly, as low a moisture content as possible should be used, since the higher the moisture, the greater the volume of steam produced in the mould with more danger of blows and poor casting finish due to sand sticking to the pattern. A higher moisture content is usual with fine-grained, natural bonded sand, and for dry sand moulds, though high moisture can lead to over ramming of the mould with a possibility of poor permeability, scabs and buckles on the mould surface.

The breaking up of a mould surface under the sudden heating effect of the molten metal entering the mould can be due not only to sudden expansion of steam in a mould of low permeability, but also to expansion of the sand grains themselves in a mass with low deformation or "give" (F. Hudson, "Composition and Its Effect in Properties of Mould and Core Sand Mixtures at Elevated Temperatures," *Proceedings of the Institute of British Foundrymen:* 1936-37; S. Carter and A. W. Walker, "Moulding Sand with Special Reference to Blind Scabs," *Foundry Trade Journal*, May 26, 1938, p. 423). Whilst natural bonded sands are usually worked at between 5 and 7 per cent moisture, synthetic sand mixtures are worked considerably lower, averaging about 3 to 3·5 per cent with colloidal clays of the bentonite type. Examples of mixtures in use for various types of work will be found in Tables 7.3 and 7.4.

SAND GRADING OR MECHANICAL ANALYSIS OF SANDS

In any method of grading sands the particular grades refer to a certain limited size of particle. Thus the true clay grade is usually specified as consisting of particles less than 0·01 mm. diameter. Table 7.5 shows the system of classification put forward by Professor T. Boswell, who divided the whole range of sand particles into eight grades. For most foundry

TABLE 7.4

MOULDING SANDS USED FOR CAST IRON, SHOWING VARIATION IN COMPOSITION AND PROPERTIES*

Type of Casting	*Ratio new sand to old*	*Ratio coal dust to sand*	*Moisture per cent*	*Green compression str. lb. per sq. in.*	*Green permeability A.F.A. No.*	*Dry compression str. lb. per sq. in.*
Light:						
Minimum	1–100	1–500	3·5	2·4	22·0	24
Maximum	1–1	1–5	8·0	6·5	46·0	100
Average	1–3	1–35½	6·0	4·8	30·0	79
Medium:						
Minimum	1–40	0	3·5	3·1	16·5	25
Maximum	1–1	1–50	7·0	10·0	53·0	200
Average	1–3½	1–18½	6·75	5·0	31·3	90
Heavy:						
Minimum	1–12	0	3·5	4·5	20·0	50
Maximum	2½–1	1–19	8·0	9·5	60·0	162
Average	1–2	1–15	6·75	5·8	35·0	95

*These values were obtained from a considerable number of individual British foundries by means of a questionnaire.

sands Boswell's grades are rather wide and it is usual, when making a detailed examination of a sand, to split up the same range of sizes into twelve grades, as shown also in Table 7.5.

The separation of various sizes of particles can be carried out either by the elutriation method used by Boswell, or by mechanical sieving through a series of sieves with standard sized apertures (Fig. 7.10 shows one type of mechanical sieve-shaker, and Fig. 7.11, a Crook's type elutriator). With clay bonded sands it is usual to free the clay from the sand grains by washing, followed by the sedimentation and decantation process, or the use of an elutriator, to remove the clay, collecting the clean sand grains for mechanical sieving on a suitable range of test sieves.

The wet methods of separating particles of different sizes are based on the laws governing the rate of fall of spherical particles in still water (Stokes's Law states Velocity $\propto$ D_2). In the elutriator the sample is acted on by an ascending column of water, the velocity of which can be adjusted so as to carry away all particles below a certain size. By subjecting

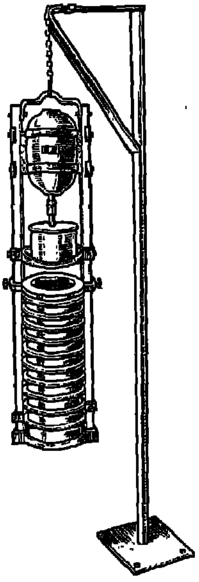


FIG. 7.10. *Coombs' gyratory sifter.*

TABLE 7.5
GRADING OF SAND GRAINS

Boswell's classification		*Test sieves—B.S.S.* 410–31	
Grade	*Particle size limits mm.*	*Mesh number*	*Aperture mm.*
Gravel	Greater than 2·0	8	2·057
Very coarse sand	Between 2·00–1·00	10 16	1·676 1·003
Coarse sand	Between 1·00–0·50	22 30	0·699 0·500
Medium sand	Between 0·50–0·25	44 60	0·353 0·251
Fine sand	Between 0·25–0·10	72 100 150	0·211 0·152 0·104
Coarse silt	Between 0·10–0·05	200 300	0·076 0·053
Fine silt	Between 0·05–0·01	—	—
Clay grade	Less than 0·01	—	—

the samples to a succession of separations with different velocities of water, a series of portions of grains of the selected size group can be collected, dried and weighed. Elutriation is a slow method compared with sieving, unless a number of elutriators are operated simultaneously, but the results are not so liable to the inaccuracies which may easily creep in with sieve testing. Several forms of standard sieves have been adopted from time to time by different authorities, but B.S.I. standard sieves (No. 410/31) are now used by British foundry laboratories for sand testing. These sieves all have square apertures, the dimensions stated being the length of side of the opening.

PROPERTIES AND CHARACTERISTICS OF MOULDING SANDS

The most important physical properties are summarized under the headings: Plasticity, Green Bond, Dry Bond, Permeability, Refractoriness. These properties are more or less interrelated with one another and with the lesser known properties of sands at high temperatures. Flowability and deformation of moulding sands are also closely related with the working character of the sand and are receiving increasing attention in sand research. Apart from economic considerations of price and availability of supplies, these properties must be assessed when deciding on the suitability of a sand for moulding purposes.

Under the action of the rammer, jolting or squeezing machine, the mass of sand must flow and pack round the pattern, reproducing exactly its shape and retaining the same after removal of the pattern. This property of sand to assume any shape without losing its coherence is described by the term plasticity, and in attempts to measure this quality of moulding materials, the terms green strength, flowability,. and deformation value have arisen. The packed mass of sand grains in a mould must have sufficient coherence or bond in the green state, not only to prevent sagging or collapse of the mould during handling, but also to withstand the wash and pressure of the liquid metal as it flows down the runner and into the mould cavity. Flowability indicates the facility with which movement is transmitted through a mass of sand and is a desirable property for machine moulding or in moulding deeply recessed or undercut patterns, as, for example, a deeply finned engine cylinder.

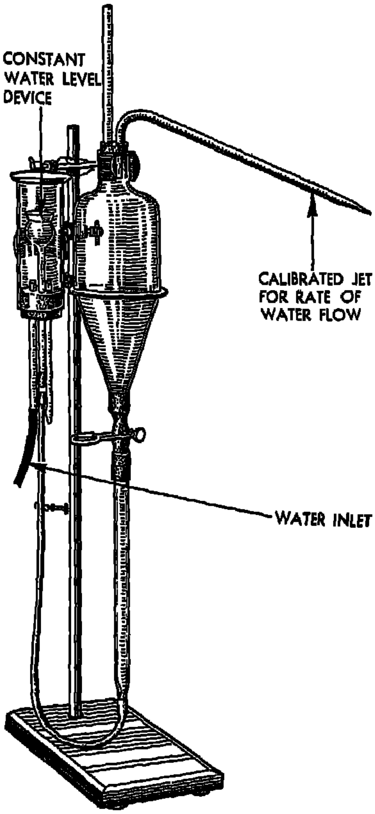

CONSTANT WATER LEVEL DEVICE
CALIBRATED JET FOR RATE OF WATER FLOW
WATER INLET

FIG. 7.11. *Crooks' elutriator for determining the grading of sands.*

A moulding sand possessing a high deformation value (see p. 242) can undergo appreciable change in volume under load, without collapsing, and so gives adequate flexibility to a mould to take up uneven joints, swelling, or expansion of parts of the mould without collapse or cracking. For routine testing the green strength of sand is now usually measured by the compression test and the same test can conveniently be adopted for evaluating deformation and flowability as recommended by W. Y. Buchanan in his papers on sand testing (*I.B.F. Proceedings*). Buchanan's work on this subject shows that these working qualities of moulding sands are affected, not only by the moisture content and character of the clay bond, but also by the efficiency of milling of the sand.

As molten metal enters a green sand mould a very large volume of gas is generated in the sand at and near the mould face due to conversion of moisture into steam, and also to the decomposition of organic matter or coal dust in the sand and expansion of gases. The sand mould must be sufficiently permeable to allow such gases to escape rapidly to the outer surface of the mould or they will seek to escape through the solidifying metal and probably cause porosity in the casting.

When the sand mass becomes dry, either under the heat of the metal entering the mould, or when artificially dried in the foundry oven (stove), it must still retain adequate dry bond or strength to withstand the pressure of the liquid metal without crumbling or washing away, and in the case of dried moulds and cores to stand handling, moving, etc., without damage. At the same time the mould, or core, must not be so strong as to seriously resist the contraction of the cooling casting, which, in the period following partial, or even complete, solidification, is still mechanically very weak and easily broken. For this reason high dry strength in the mould is not desirable in many instances, as, for example, when casting metals such as steel which have a high contraction value, or thin section white iron castings. This problem is more directly connected with the hot strength or properties of sand at high temperature, e.g. hot strength (see "High Temperature Testing of Moulding Sands," W. B. Parkes and R. G. Godding, *I.B.F. Proceedings*, 1955). The refractoriness of a sand should be sufficiently good to prevent any serious fusion or softening of the mould and core surfaces by the heat from the cast metal in order to produce a casting with a clean skin, and avoid, as far as possible, costly cleaning or fettling.

OIL-SAND TESTING AND CONTROL

(1) *Testing of New Sands*, as distinct from the routine control testing of the prepared sand mixtures in the foundry, is a laboratory job. It is important that the sample to be tested should be representative of the bulk of sand, and it is, therefore, usual to take a number of samples from different parts of a load or heap, mix together and quarter down until a reasonably sized sample for final preparation is obtained. Recommendations for sampling of sands have been published by the Committee on Moulding Sand Research of the A.F.A. in their handbook on "Testing Foundry Sands."

Preparation of Sample for Testing. The new sand will require milling to obtain uniform distribution of the bond, preferably in a laboratory size sand mill, where it is tempered with water to the required percentage for testing. After tempering the sample should be stored in an airtight container for 24 hours before testing for bond, permeability, and dry strength by the usual routine methods. These tests should then be repeated at various moisture contents. Determination of clay content and grading of the washed sand is made on a weighed sample, say 100 grams, by either elutriation or the sedimentation and decantation method (Fig. 7.12 shows a rapid sand washer). The full series of grades are then reported as weight percentages. Chemical analysis and refractory cone tests are only needed in exceptional circumstances, and methods of procedure will be found in textbooks dealing with refractory materials.

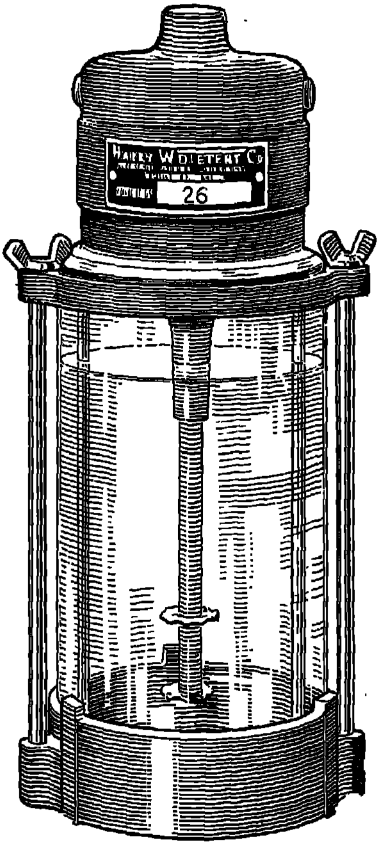


FIG. 7.12. *Dietert rapid sand washer for testing clay-bonded moulding sands.*

(2) *Routine Testing of Prepared Sand.* In order to control the quality of sands in the foundry, simple and rapid tests have been developed for measuring moisture content, green and dry bond, permeability and grading, and examples of some of the equipment now available are shown in Figs. 7.12–25.

Moisture Content is determined either by the standard laboratory method of drying to constant weight at 110 deg. C. or for rapid control testing by using the moisture teller (Fig. 7.13) or the "Speedy" moisture meter. In either of these instruments a test can be completed in two to three minutes.

Green Strength. Four types of test have been used to measure the green bond strength of sands. These are the compression, shear, tensile and overhang bar tests. Of these the compression test is by far the most widely used, and is very convenient for routine testing of all types of natural bonded and synthetic moulding and core sand mixtures. The test may conveniently be considered in two parts: (*a*) preparation of the test specimen, and (*b*) making the compression test. The 2 in. diameter by 2 in. high standard test piece which has a volume of 103 cm.^{3} and a cross-section

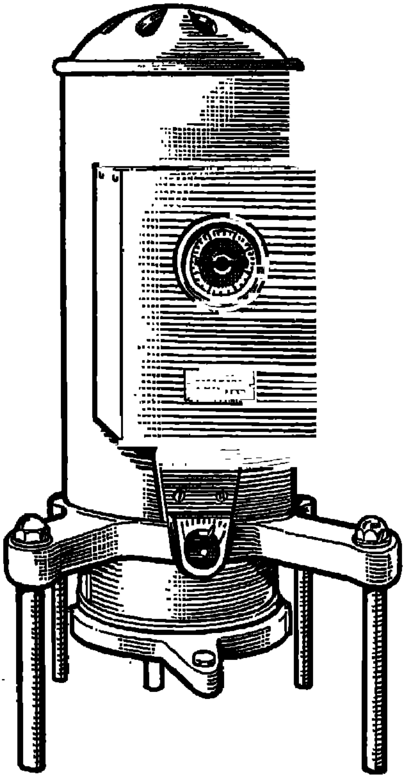


FIG. 7.13. *Moisture teller.*

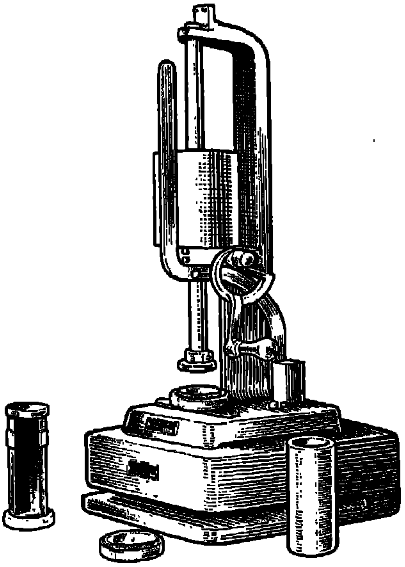


FIG. 7.14. *Dietert standard rammer.*

of 3·142 sq. in. is prepared by ramming the required quantity of sand in a smooth-surfaced tube with three blows of a standard rammer (Fig. 7.14). The blow of the rammer is delivered by a weight of 14 lb. falling a distance of 2 in., and the quantity of sand in the tube is adjusted so that the test piece finishes within $\pm\frac{1}{32}$ in. of the standard 2-in. length, as indicated by the gauge marks on the rammer. The test piece is stripped from the tube on a stripping post and transferred to the compression-testing machine. The same standard-test specimen is used for the determination of dry compression strength and green and dry permeability.

Double Compression Method. This is an alternative method of preparing the test piece, and was put forward by Buchanan. As its name suggests, the sand test piece is rammed first from one end, then from the other, not with a constant degree of ramming, but to a predetermined relative density or ratio of weight : volume. This method of ramming produces a much more uniformly compacted specimen, and the relative density or degree of ramming can be made to compare closely with that of a mould prepared in the foundry, or, at least, with some particular part of the mould.

This is because we know that in actual practice the density or degree of ramming may vary considerably in different parts of a mould. It should be borne in mind that the standard rammed test piece may bear no direct relationship to the actual mould but merely serves as a means of comparison or control of the bond, etc.

Compression Test. Three principal types of compression-testing machines are in use in Britain, the B.C.I.R.A. modified spring balance type (Fig. 7.15), the Dietert Universal sand strength machine (Fig. 7.16). and the Fischer strength-testing apparatus.

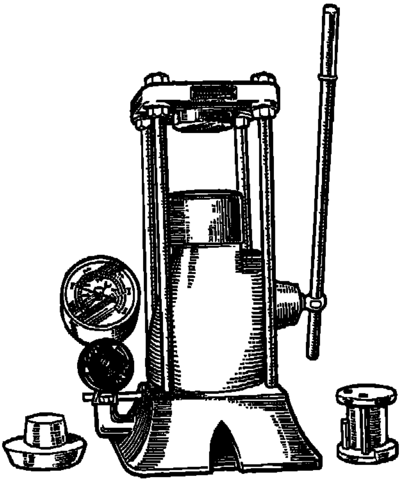


FIG. 7.15. *Sand compression tester.*

In each the load is gradually increased by means of a hand wheel until the specimen collapses. The total breaking load in lb. divided by the cross-sectional area of the test piece in sq. in. gives the green strength in lb./sq. in. Provided precautions are taken to ensure axial loading of the test piece, and absence of friction or vibration, comparable results are obtained on all three types of machine. The rate of loading is not critical but should be uniform and of the order of 1 lb./in.^{2} per sec.

This test can be used to measure the deformation value of the sand at the same time as its compression strength, by means of a simple attachment to the machine which accurately measures the reduction in length of the test piece when loaded to the point of failure.

Shatter Index. This is an empirical test devised as a routine test for assessing

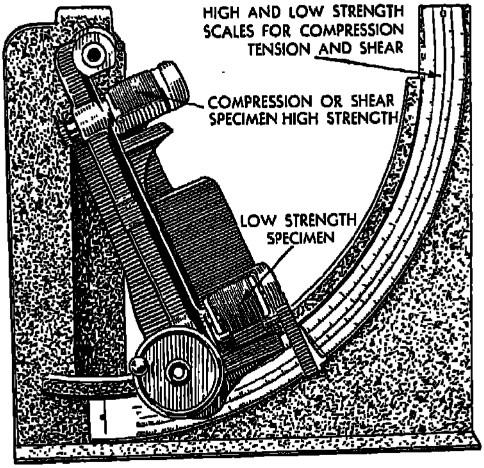

HIGH AND LOW STRENGTH SCALES FOR COMPRESSION TENSION AND SHEAR
COMPRESSION OR SHEAR SPECIMEN HIGH STRENGTH
LOW STRENGTH SPECIMEN

FIG. 7.16. *Dietert Universal sand strength machine.*

the toughness or mouldability value of a prepared sand, utilizing the standard 2 in. diameter by 2 in. high standard rammed specimen. The equipment illustrated in Fig. 7.17 is designed to drop the sand test piece from a height of 6 ft. on to a steel pedestal and then collect and weigh the sand which remains on a ½-in. mesh B.S. sieve. The shatter index is calculated as the percentage weight of sand remaining on the ½-in. sieve. This value gives a useful guide not only to the mouldability of a sand but as a check on the uniformity of sand preparation, since it varies with moisture content, clay content and efficiency of milling.

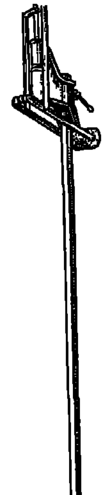
Dry strength of moulding sands is generally measured by a compression test using the same form of test piece and methods of preparation described for the green compression test. After stripping from the specimen tube the test piece is transferred to a suitable drying oven and completely dried so as to obtain maximum strength. The drying temperature will vary somewhat according to the type of sand. Some sands decrease in strength if heated much above 150 to 170 deg. C., whilst others may give better results over 200 deg. C., so that with an unknown sand, tests should be made at various temperatures from 150 to 250 deg. C. to find the best condition. A drying time of one to two hours is usually ample, and the oven should be capable of maintaining a steady temperature within ± 10 deg. C. over the range and be ventilated to give at least ten air changes per hour.

On removal from the oven the test piece is allowed to cool down to room temperature, preferably in a desiccator, or it may be tested while it is still just warm, since moisture absorption from the atmosphere appreciably reduces the dry strength of sands.

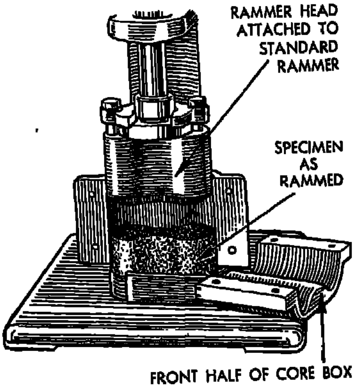
The compression-testing machine for dry sand tests is usually one of the same three types used for green strength but equipped for considerably heavier loads, say up to 1,000 lb./sq. in. Several types of machines for carrying out the compression can be adapted for tensile and transverse tests. A steadily increasing load is applied to the specimen until it collapses, when the breaking load in lb., divided by cross-sectional area of the test piece, gives the dry compression strength in lb. per sq. in.

OIL-SAND

Owing to the much higher dry compression strength of many oil-sand mixtures, a tensile or transverse test is often used as being well within the range of a small machine. The tensile test piece is also more sensitive to changes in sand grading, grain shape and other variables affecting performance in the foundry, and is therefore to be preferred in most cases. Fig. 7.18 illustrates a suitable machine. The test piece can be prepared by means of the standard rammer fitted with a suitably shaped ramming head (7.19).

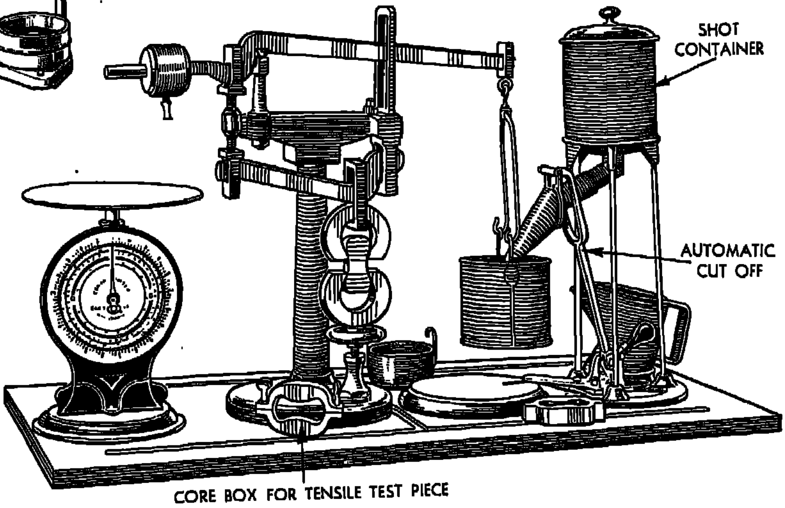


(Left) Fig. 7.17. *High compression strength machine for dry sand and oil-sand.*



(Below) Fig. 7.18. *Tensile test equipment for oil-sand dry-strength testing.*

(Above) Fig. 7.19. *A rammer and corebox for preparing specimens of dried core sand.*



Drying conditions for oil-sand test pieces vary according to the type of binder and the grade of sand, and best conditions must either be found by experiment under the particular oven conditions or according to shop practice. Most mixtures can be baked in the region of 200 deg. C., but the oven should be equipped with some method of circulation or distribution of the heated air in the stove. (Fig. 7.20.)

PERMEABILITY

This is expressed as the volume of air (cu. cm.) that will pass in unit time through unit area of sand under unit pressure. It is determined by

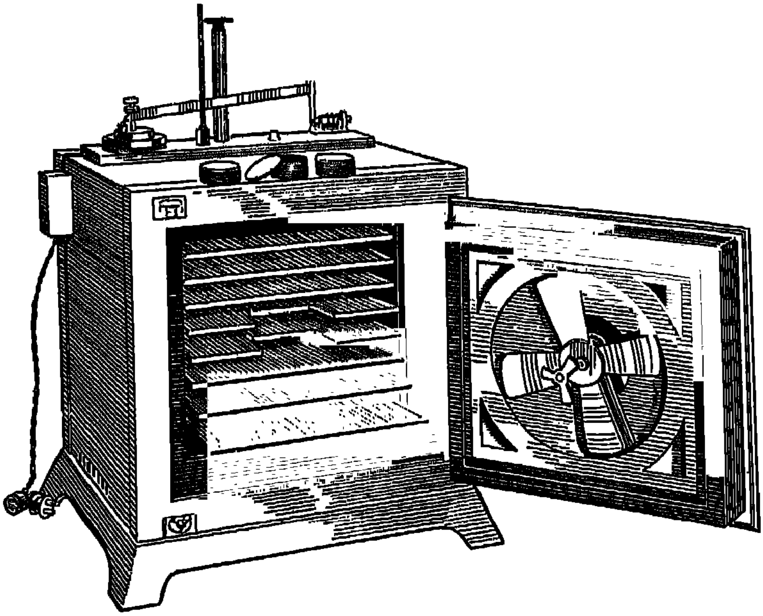


FIG. 7.20. *Laboratory oven for baking oil-sand test-pieces.*

measuring the rate of flow of air through a standard specimen of sand under a given pressure. The permeability apparatus (Figs. 7.21 and 7.22) uses the standard rammed 2-in. diameter by 2-in. test piece. For green sand tests the test piece is left in the tube after ramming in the usual way, and the tube is transferred to the mercury seal cup at the base of the apparatus. The time for a known volume of air (one or two litres) to pass through the test piece is measured whilst the pressure on the face of the specimen is indicated by a simple manometer in circuit.

For rapid working, a standard calibrated orifice can be fitted into the air line below the specimen and the back pressure, indicated by the manometer, gives the permeability number direct by reference to a movable scale on the permeability apparatus.

The permeability number is given by the formula $P = \frac{v\,h}{p \times a \times t}$

Using 2,000 cu. cm. air at a pressure of 10 cm., the formula becomes $P = \frac{3{,}007}{t}$

Where P=permeability number; v=volume of air passed; h=height of specimen; p=pressure in cm. water during test; a=cross-sectional area of specimen; t=time in seconds.

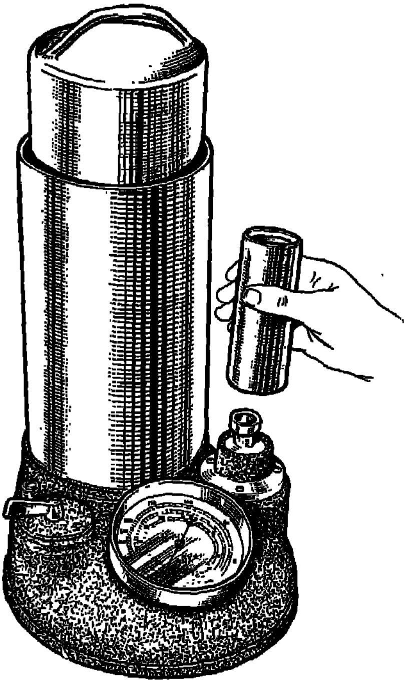


FIG. 7.21. *Direct-reading Fischer permeability meter.*

The permeability of dried test pieces is obtained by using a special form of container into which the standard 2-in. diameter test piece is placed (Fig. 7.23). It is pressed down on to a rubber ring by means of a clamping screw, and mercury is used to form the seal around the sides of the specimen. The container is then placed in the mercury cup on the permeability apparatus and the test completed in the usual way. By this means the permeability of oil-sand, loam, or any form of moulding material, used in the dried condition can be measured.

The determination of the refractoriness or fusion temperature of a sand calls for some form of high-temperature furnace and requires considerable skill and experience to obtain accurate results. A special furnace, in which the heating element is a piece of platinum ribbon, is used to some extent in the U.S.A. for this purpose. The method in general use for evaluation of refractory materials by comparison with a series of standard test cones enables comparison of softening or fusion temperature of several sands to be made at the same time.

The loss on ignition of a sand is a useful form of control test both in the case of moulding sands containing coal dust and for any sand used for cores as an indication of the amount of gas-forming matter present. Of course, in the case of natural bonded sands the loss on ignition will also include combined water and organic matter present in the bonding clay, but a fairly simple calculation can be made to check the coal dust content knowing the composition of the coal dust in use.

In the foundry the actual hardness, or degree of ramming of moulds, is usually simply measured by means of resistance to penetration of the thumb or finger. This test is made more scientifically, and a numerical value given, by using a mould hardness tester. This tester has a steel ball in its base, which is pressed down into any part of the mould face (Fig. 7.24) and the resistance to penetration indicated on a clock dial. Further tests on actual production moulds can, of course, be obtained by cutting out a standard-sized test piece with a suitably shaped tube and trimming to length before testing for permeability, green bond, etc., in the usual way.

DEFORMATION VALUE AND FLOWABILITY OF SANDS

These terms refer to certain properties of a sand mass which are included in the general term "plasticity." A sand which possesses a rather high deformation value can undergo appreciable change in volume under load without collapsing, such a feature giving flexibility to a rammed mould to take up uneven joints, swelling or expansion of the mould wall, when heated. Dietert in America, and W. Y. Buchanan in Great Britain, were responsible for the earlier work on measuring these properties of sand and adopted the compression test to indicate the deformation value, by accurately measuring the reduction in length of the test piece when loaded to the point of failure.

Flowability describes the facility with which movement is transmitted through a mass of sand and is a desirable quality for easy ramming of sand round deeply recessed, overhung, or narrow finned patterns, for core-blowing mixtures, and high-speed moulding work. For measuring flowability of sands Buchanan uses a cylindrical test piece 1⅛ in. diameter by 2¼ in. long, of the same apparent density as the standard rammed A.F.A. compression test piece but prepared by a single compression from one end only. Using a Dietert hardness tester (see Fig. 7.25) the hardness of each end of the

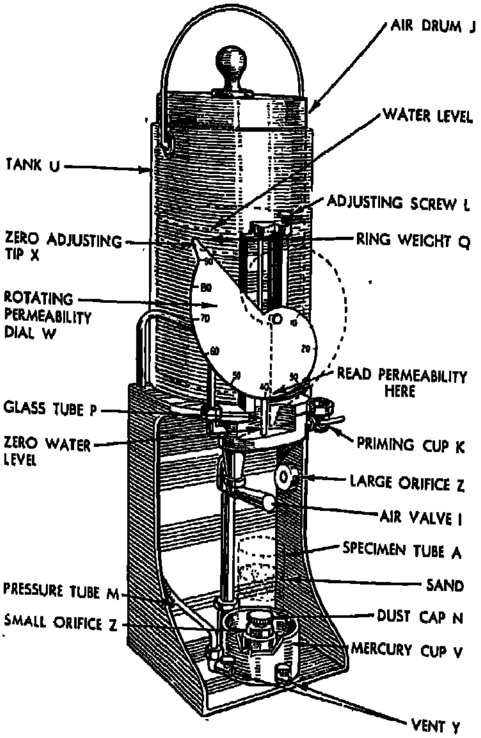
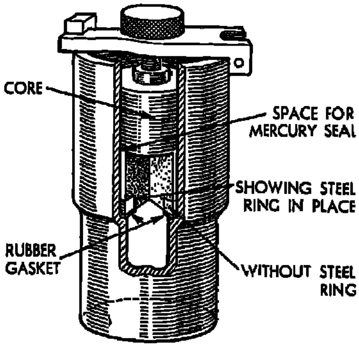


FIG. 7.22. *Dietert permeability meter for making green-sand permeability tests.*

FIG. 7.23. *Specimen tube for testing permeability of dried sand specimens.*



specimen is measured and the flowability number taken as the ratio of top to bottom hardness expressed as a percentage, i.e. if of equal hardness, flowability = 100 per cent.

A recent modification of this method known as the Rowell Test uses the standard 2-in. diameter specimen tube, into which is placed a special metal plate so shaped that it stands at an angle of 60 deg. inside the tube, thus producing a sand specimen with a sloping face. After stripping from the tube, the test piece is supported on a curved metal carrier and mould hardness is determined at points near the top and bottom of the inclined face. Flowability is calculated as before from the ratio of the two hardness values. A value of 70–75 is considered good, and below 65 unsatisfactory for general moulding.

The limited amount of research work so far carried out on the properties of sand show that they are interrelated and are affected, not only by the moisture content and character of the bond, but also by the efficiency of milling of the sand and the sand grain shape. A sand with high plasticity has low flowability and vice versa, hence for general moulding properties a compromise must be made between high flowability and high deformation or plasticity. (See *British Foundryman*, vol. 1, part 2, p. 62, "Flowability of Foundry Sands.")

STEEL FOUNDRY SAND PRACTICE

So far as refractories are concerned, one of the most outstanding features in steel founding is the high temperature at which molten steel is cast, ranging from 1,550 to 1,700 deg. C. All mould and core materials

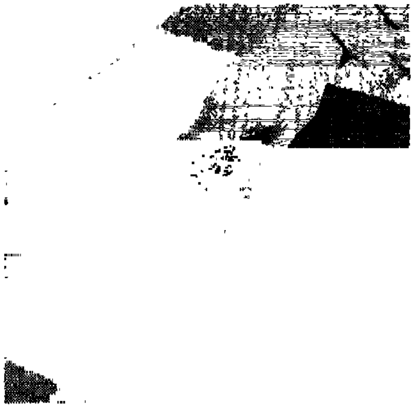


FIG. 7.24. *Mould-hardness testing.*

TABLE 7.6 COMPARISON OF SOME SILICA SANDS USED AS CORE AND MOULDING SANDS FOR STEEL CASTINGS

Class of sand	*Southport dune sand per cent*	*King's Lynn silica per cent*	*Chelford silica per cent*	**Leighton Buzzard per cent*	*Ryarsh silica per cent*
Sieve test, 1 mm., Sieve No.:					
Remains on 22	nil	0·15	0·4	3·0	nil
Remains on 30	0·03	3·75	1·8	15·6	0·05
Remains on 44	0·8	31·65	13·5	58·4	0·22
Remains on 60	15·0	25·4	33·9	21·4	0·62
Remains on 72	21·4	16·95	22·4	1·1	1·67
Remains on 100	47·2	17·0	17·4	0·4	3·0
Remains on 150	15·4	4·7	8·7	0·1	67·8
Passes through 150	0·15	0·3	1·9	trace	26·4
Clay and silt (washing test)	—	up to 2·6	2·5	less than 1·0	up to 1·5
Gas content, cc. per gram	up to 10·5	1·0–1·5	0·5	up to 0·5	1·0
Per cent loss on ignition (on dry sample)	0·8–1·8	0·62	0·43	0·32	0·64
Type of grain	Mainly smooth worn grains, subangular, contains sea shell and weed	Rounded and subangular coated grains (glauconite mineral present)	Worn rounded quartz grains slight coating. High refractoriness	Worn grains rounded and subangular. Slight iron oxide staining	Very fine grained broken angular and subangular quartz particles. A little clay, etc.
Permeability A.F.S. No.	140	165	175	over 200	60

*Arnolds, No. 52.

Sieve tests on clay-free sands.

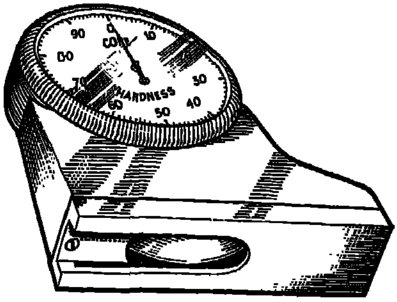


FIG. 7.25. *Core-hardness tester.*

must, therefore, be highly refractory in order to give good stripping of castings and reduce fettling as far as possible. Another factor is the danger of hot tears, or cracking of castings, brought about by mould or cores resisting the contraction of the cooling mass of steel. A high dry strength is, therefore, seldom desirable, yet the sand surface must not flake away or collapse under the heat and wash of the liquid metal.

Both natural bonded and synthetic sands are used in the steel foundry. Apart from the Scottish rotten rock sands the supply of first-class natural bonded steel moulding sand in Great Britain is limited. In the past, large quantities of Belgian moulding sand was imported by British steel foundries, but mainly for economic reasons these have been replaced by synthetic or specially prepared sands of local origin such as King's Lynn, Chelford and Leighton Buzzard sands. Work which was begun by Professor Boswell during the period 1914-18 has been continued by the moulding material sub-committee of the Iron and Steel Institute (see first report, published 1938, and second report, published in 1942), and has resulted in a far greater use of British silica sands in steel foundries. It seems likely that in time synthetic sands will be used almost universally in British steel foundries as in the U.S.A.

The bases of these mixtures are graded silica sands, usually composed of subangular type grains with roughened surfaces, sometimes carrying a small amount of natural bond. In some cases suitable sands are being produced artificially by washing and grading a natural deposit. Steel sands are usually of coarser grain size than those used in cast iron or non-ferrous foundries, and the grading of typical natural bonded and silica sands used in British steel foundries are given in Table 7.6.

We can divide steel sand practice into four main classes: green sand, dry sand, oil-sand, compo (see Table 7.7).

Green Sand. For this work a particularly permeable sand is required and thorough mixing with even distribution of moisture and bond is essential to prevent trouble with scabbing and cracking whilst working with as low a moisture content as possible and maintaining adequate green strength. A permeability figure of 150 to 200 is normal practice, with a moisture content of between 3 and 4 per cent, and a green compression value of

TABLE 7.7
EXAMPLES OF STEEL MOULDING SANDS (Synthetic)

Green sand per cent	*Dry sand per cent*	*Compo parts*
King's Lynn red 25	Levenseat silica 15	Old firebrick 3½
Old sand 75	Old sand 85	Calcined clay 2
Bentonite 1·5	Bentonite 0·5	Calcined ganister 1½
Dextrine 0·25	Moisture 5	Fireclay 1¼
Moisture 3–3·5	—	Blacklead 1 per cent weight

6 to 10 lb. per sq. in. Only a uniformly graded sand of fairly coarse grain size will give such a high permeability, and the bonding material often includes a small proportion of an organic binder such as dextrin. In synthetic green sands, bentonite, "Fulbond," or specially prepared refractory bonding clays are used.

In general, green sand is the most economical method of moulding since there is no drying cost or time spent in drying moulds, but considerable skill and technical control are called for in producing steel castings by green sand methods, and though there are foundries making castings up to 5 tons and over in green sand moulds, it is generally confined to the production of smaller castings.

Dry Sand. This is used in Britain for all ranges of castings and more than half the tonnage of steel castings produced in this country are cast in dry sand moulds. Dried moulds are considerably stronger and more rigid than green sand, moreover they will stand more handling and can be patched and the surface sleeked or sprayed with refractory washes to ensure a clean surface to the casting.

For dry sand work using natural bonded sand it is common to find two or more different sands in the mixture, one of which usually has a strong refractory bond such as the Scottish rotten rock, which frequently contains 15 to 20 per cent clay grade, mixed with a fairly coarse silica sand to give a highly permeable mixture. Synthetic dry sand mixtures generally consist of one basic silica sand with additions of bentonite, fireclay, silica flour, or dextrin.

The moisture content will vary according to the nature of the bond, but it is generally rather higher than for green sand work with permeability in the region of 200 or higher (A.F.A.). Green strength values are much the same for green and dry sand work and dry strength (compression) in the region of 100 to 150 lb. per sq. in. is normal.

Since the strength of the mould after casting is of special importance, considerable research into the properties of steel moulding materials at high temperature has been made with particular reference to the effect of various types of bonding clays (F. Hudson, Dadswell and Walker, 1939; N. J. Dunbeck, *I.B.F. Proc.*, 1941). In consequence, mixtures of two or more clays, with an organic substance such as dextrin, which is completely destroyed at temperatures above 300 deg. C., are being used in some instances.

Oil-sand. Where oil-sand is used for moulds and cores the same general properties of good refractoriness and high permeability are required, and the same types of silica sand are used as for synthetic moulding sand mixtures (see Table 7.6). The bond is supplied by additions of such organic binders as dextrin, molasses, or core gum with linseed or similar core oils. Baking of the moulds or cores is usually carried out in suitable core stoves, but owing to the difficulties of transporting and drying large moulds and cores, skin drying with torches or fire buckets in the foundry floor is often used for oil-sand as well as green sand moulds. A particular feature of moulds made from oil-sand is the almost complete loss of bond at high temperature with consequent collapse of the sand surrounding the metal. This allows for unrestricted contraction. For this reason oil-sand is widely used for building up moulds for large complicated steel castings by the assembly of separately dried cores.

Use is also made of "self-hardening" or "cold setting" core oils for large and intricate cored castings.

In some cases oil-sand is only used as a facing to the mould, the backing consisting of remilled old sand, but in other cases, where a particularly good surface finish is required, as with stainless steel and other alloy steel castings, all oil-sand is used.

Compo. This is the abbreviation for "Sheffield composition," which has been used almost exclusively for many years as the moulding medium for large steel castings. It is a synthetic mixture originally made by crushing down old crucibles and old firebricks together with ganister and fireclay. Graphite, or coke, was often added for refractoriness, and as the supply of old crucibles became scarce, substitutes such as burnt fireclay were introduced, as used in chamotte. Chamotte is a coarsely graded refractory moulding material much used on the Continent in steel foundries. It is prepared from calcined clay and ground firebrick milled with raw clay to give plasticity and rather similar in properties to compo.

The main features of such mixtures are high refractoriness with high strength at temperatures up to 700 to 800 deg. C. and above, and a very permeable structure which permits complete drying of large moulds. This also permits the ready escape of gases from the mould during casting. Owing to the open nature of compo or chamotte the moulds are given a special facing, or skin, of fine refractory material usually containing a high proportion of silica flour. The painting or dressing of the compo mould is particularly important and calls for skilled labour. For drying, the moulds are loaded on to bogies or plates and put into large stoves, where they are gradually heated to dull redness, and after soaking the required time cooled down slowly before returning to the casting floor. Modern drying plant is usually equipped with temperature recorders and the control of drying time and temperature enables troubles which may be caused by over or under drying to be avoided.

Cement Sand Practice. The use of Portland cement as a moulding material was experimented with in the U.S.A. some twenty-five years ago, and in recent years the Randupson process of cement moulding has been taken up by a number of steel, iron and non-ferrous foundries in Europe. The Randupson process was developed in a French steel foundry and makes use of the first set, or hardening, of a sand-cement-water mixture which takes place in about 24 to 48 hours from the time of mixing. The mixture used for moulding consists of a well-graded, clean silica sand, as used for other synthetic sand mixtures, mixed with about 10 per cent Portland cement and about 4 to 6 per cent water.

The damp mixture remains in a fit state for moulding for two to three hours after mixing. After moulding, half moulds are stripped on to plates and stored in a humid atmosphere to cure, or set, for about 18 to 24 hours. They may then be dried off more rapidly until completely hardened. The moulds are then assembled and cast in the usual way, the interval between moulding and casting being from 36 hours upwards, according to the type of cement and foundry conditions.

The new mixture of sand and cement is generally only used as a facing and old crushed moulds form the major part of the backing sand, with small additions of new cement. This process is particularly suited to the production of heavy castings, such as marine propellers, since the hardened cement sand has high mechanical strength and allows much thinner mould walls to be used than normal, whilst a high permeability is maintained. Other claims for the process are a big saving in labour costs since unskilled labour can be largely used, no drying stoves are required, and the time for moulding is much reduced (F. Rowe, *I.B.F. Proceedings*, 1937-38).

The CO_2 process and shell-moulding process are both applied to a limited extent in the production of steel castings. For shell-moulding clean silica sands of fine grain size such as Redhill H or Chelford fine

TABLE 7.8

FACING SANDS FOR GREEN SAND CASTINGS

Type of sand	*Green sand facing for heavy cast iron*	*Green sand facing for medium cast iron*	*Green sand facing for light cast iron*	*Steel green sand*	*Steel dry sand facing*
COMPOSITION	28 Pickering 66 Old floor sand 6 Coal dust	20 Midland red 76 Floor sand 3–4 Coal dust	25 Erith medium loam 60 Floor sand 10 Belfast red 5 Coal dust	25 King's Lynn red silica 75 Old sand 1·5 Bentonite 0·25 Core gum	85 Yorkshire yellow 15 Northern rock sand
MOISTURE	6–7	5·5–6·5	6–7	3–3·5	7–7·5
GREEN BOND	8–10	5–5·5	4·5	7–9	8–9
PERMEABILITY	30–40	35	30	170–180	110–120
DRY STRENGTH	90–100	70–80	60–70	50–75	140–150

washed are used, bonded with powdered synthetic resin or precoated with liquid synthetic resin. Zircon sand is also used for casting small, intricate, alloy-steel castings where fettling is difficult and a fine finish essential. For the CO_2 process a clay-free, medium-grain-size silica sand is preferred as for oil-sand practice. Further information on this subject will be found in Chapter 11.

IRON FOUNDRY SAND PRACTICE

Wide variations will be found in sand mixtures used in British iron foundries (see Table 7.8), but the bulk of castings are still made with naturally bonded sands, often with some small addition of a powerful bonding clay such as bentonite. The general tendency has been to use sands of moderately fine texture, and in consequence most iron foundry floor sand is of rather low permeability. Green sand moulding is in general use for all types of ordinary grey iron and malleable castings, stove plate and repetition foundry work. Dry sand practice is used mainly for large high-quality engineering castings. These large moulds, made in the foundry floor in pits, are dried by means of portable mould dryers placed so as to force hot air through the mould.

In most green sand and dry sand work separate facing sand is used (see Table 7.3) to which coal dust is generally added except for iron castings which are to be vitreous enamelled. The proportion of coal dust varies from 3 up to 10 per cent, or even higher, for very heavy castings, and usually averages about 5 to 6 per cent for small and medium castings (see Tables 7.3 and 7.4). In general, the larger or heavier the section of metal, the coarser the grade and the higher the percentage of coal dust used. Various grades of coal dust are available from coarse to superfine which are produced from coal of low ash content and high volatile matter. A good quality coal dust should have a volatile matter not less than 30 per cent and a maximum of 10 per cent mineral ash.

Briefly summarizing the effects of coal dust in moulding sand, probably the most important is the evolution of coal gas and products of distillation and decomposition of coal particles at, or near, the face of the mould because of the heat from the molten metal. Deposited carbon acts as a refractory coating to the sand grains and prevents surface fusion, except directly against the casting where temperatures rise sufficiently to burn out all carbonaceous matter. The gaseous products which burn in the mould cavity and at the vents appear to form a protecting film between metal and sand. Coal dust in this way has a marked influence in producing a smooth bright skin to the casting. Added to this the tarry oils deposited in cooler parts of the mould, after being distilled at, or near, the mould face, play a valuable part in increasing the dry strength of the sand, which increases with continued re-use of the sand to as much as 50 per cent in some cases.

Only a limited amount of the coal dust present in a mould is subject to the effect of heat in the layer of sand within a short distance of the metal, and where a special facing sand is not used, i.e. in a unit sand system, a regular small addition of coal dust, as well as bonding material, is sufficient to make good the loss.

Whilst in green sand the moisture content rarely exceeds 7 per cent, and usually runs between 4 and 6 per cent, in dry sand practice a higher range of 7 to 9 per cent moisture is usual with natural bonded sand, and to improve the permeability of the mould a more open backing sand is commonly used and adequate artificial venting with vent wire or tube may be necessary. This is particularly the case when using some of the finer red moulding sands, such as Mansfield or Erith loam sand.

LOAM

Loam is a special strong sand mixture often containing a proportion of refractory fireclay, or ganister, which is used for moulding heavy iron castings. The ingredients are milled in a heavy edge runner mill with sufficient water to form a mud. This is applied as a plaster, or surface layer, to the rough structure of the mould which may be built of soft firebrick or dried loam bricks. The wet loam must be sufficiently adhesive to hold on to vertical surfaces without running or peeling off, and horse hair, chopped straw and manure is commonly used to assist in binding the mixture. The moisture content of prepared loam is about 20 per cent, and after careful drying the loam mould possesses a high strength.

In the south, Erith loam is probably the best known ingredient, whilst in the north, red sands, rock sands, and river gravels are milled down to produce loam. Owing to the very low permeability of loam the mould must be dried very slowly and completely before it is ready to cast. It is, therefore, a slow process and calls for experienced and skilled moulders. Loam moulding is still used to a limited extent in Britain, where the nature of the casting lends itself to this form of construction, as, for example, large regular-shaped castings such as chemical pans, drums, etc., but the use of oil-sand, cement sand, and CO_2 process sand has, to a large extent, replaced loam moulding in many jobbing foundries.

Typical mixtures and properties of loam are given below.

Type 1		*Type* 2	
Floor cake	10 vols.	Leighton Buzzard Silica sand	22 vols.
New loam sand	10 vols.	Clay	5 vols.
Silica sand	3 vols.	Manure	1 vol.
Ganister	3 vols.	Moisture	18–22%
Manure	2 vols.	Dry strength 150-250 (compression) lb./sq. in.	
Mineral blacking	2 vols.	Permeability No. less than 5.	

SYNTHETIC SANDS USED FOR IRON

Synthetic moulding sands used for iron founding are prepared from silica sand of finer grain size than those used in the steel foundry, and generally of similar type to those used for oil-sand cores in the same foundries. To mention a few examples, Leighton Buzzard medium (No. 26), Southport sea sand, Erith silica, Redhill F, and Bedford silica sand are in this class and are used with 3 to 5 per cent of bentonite, Fulbond or other bonding clay with the usual percentage of coal dust (see Table 7.9).

Oil-sand is used to a considerable extent in the mass production of intricate castings for automobile and aero-engines, etc., where the mould is built up with the aid of a number of accurately dimensioned cores or oil-sand blocks. The particular type of sand used generally depends on the available local supplies. Southport sea sand and Congleton silica are the most widely used in the Midlands, whilst for many purposes, where a fine surface and good green bond is required, it is usual to add from 5 to 10 per cent of a red moulding sand, such as Bromsgrove, Mansfield, or Belfast, to the mixture.

TABLE 7.9 SYNTHETIC SAND MIXTURES IN USE FOR CAST IRON

In British Foundries—Green Sand Moulding

Sample No.	1	2	3	4	5	6
Type of base sand used	Leighton Buzzard	Southport sea sand	Sea sand and Leighton Buzzard bank sand	Erith silica sand	Leighton Buzzard No. 26 or Bedford silica	Scottish rotten rock
Particulars of mixture	*System sand* 99·4 Old sand 0·56 New sand 0·06 Bond clay	54 Old sand 36 New sand 4 Fulbond 6 Coal dust	91 Backing sand 3 Bentonite 6 Coal dust	*System sand* 99·7 Old sand 0·25 New sand 0·05 Bentonite	70 Old sand backing 20 New sand 3·5 Colbond 6·5 Coal dust	*System sand* 97 Floor sand 1 to 3 Rock sand 0·7 Coal dust 0·1 Wood extract
Class of work	C.I. baths for enamelling	Pot castings, high duty iron	Light castings (facing sand)	Light castings in high duty iron. 70 per cent steel	Automobile cylinder castings. — Facing sand	Hydraulic engineering castings. Hand and machine moulding
Moisture, per cent	3·0	3·0–3·5	3·5	3·8	4·0	6·0
Green compression str., lb. per sq. in.	4·5–5·0	6·0	9·5	5·9	8·0	6·0
Green permeability, A.F.S. No.	60–70	70–75	70	65	50–60	53

CO_2-process sand is being used increasingly for both moulds and cores in British iron foundries, having replaced dry sand moulds to a considerable extent in jobbing work.

NON-FERROUS SAND PRACTICE

In general, the moulding sands used in the non-ferrous industry are similar to those used for cast iron, with a few notable exceptions, as in the case of magnesium alloys.

The main difference in practice being the result of: (1) the general lower casting temperatures used, which results in a longer life of the bond in the sand, and (2) the searching nature of the non-ferrous alloys, and the desire to obtain a good casting finish, leading to the use of as fine a sand as possible.

In order to maintain reasonable permeability with a fine grain size, uniformity of grain is essential. The finer and more regular the grain size, the better the casting finish, and, in the past, certain sand became justly famous for brass and bronze casting. These include the finer types of red sand, such as occur in the Midlands—Birmingham, Kidderminster, Bromsgrove—Mansfield and Belfast, and in the south, Erith loam. Mansfield red moulding sand is used from north to south for both green sand and dry sand moulding for brass, phosphor-bronze, aluminium-bronze, manganese-bronze, nickel alloys, and in the aluminium foundry.

Green sand is general practice for all types of small and medium weight castings, the moisture content being kept on the low side of the optimum value for maximum dry strength, or plasticity; 4 to 5 per cent is usual, and permeability is often as low as 20 to 30 with a green bond (compression) of 4 to 5 lb. per sq. in. Facing sand seldom requires any large addition of new sand to produce sufficient bond, but owing to the loading up of the floor sand with metal shot and dross, non-ferrous plant sand can easily become clogged and of poor texture unless efficiently screened and reconditioned.

In the aluminium foundry it is usual to find the floor sand being used over and over again with very little addition of new sand except for cores or special facing mixtures. Mixing rather than milling is often all the treatment the sand receives apart from tempering to the required moisture percentage.

With alloys such as phosphor-bronze, which are not protected by an oxide skin when being poured, and which tend to penetrate the mould face, the use of a fine-grained sand is essential where any weight of metal is cast, and a special dressing or paint is generally brushed, or sprayed, over the surface of moulds and cores to prevent this penetration. Fine plumbago, or blacking, is also sometimes mixed with the sand for the same purpose, and further reference to this will be found in the later section dealing with blackings.

For high-quality castings for Ordnance, Admiralty, and pressure work in various types of bronze, dry sand practice is favoured as giving more accurate dimensioned castings and ensuring greater freedom from inclusions, dirt and general porosity, the same is true of the CO_2 process. Half-moulds are moulded by hand, or on simple roll-over machines, then sprayed all over with a suitable mould paint before drying.

Oil-sand is in fairly general use for core making in non-ferrous foundries mainly because of better venting and easier fettling after casting. The advent of mechanical core making (core blowing, etc.) with oil-sand has also speeded up production of small cores on mass production lines. Mixtures usually contain a proportion of naturally bonded sand which may be as high as 30 or 40 per cent in some cases, but the tendency is to reduce this proportion to a minimum to obtain an easier knock out and high permeability in the core.

For larger non-ferrous castings cores are frequently made with normal moulding sand. Dry sand moulds must be given a coat of core paint before stoving or skin drying.

SYNTHETIC SAND PRACTICE

Something has already been said of the artificially bonded sand mixtures used more particularly for steel founding, but also to a considerable extent in mechanized iron foundries.

Table 7.9 gives details of synthetic sand mixtures in use for various types of castings, although the term synthetic sand is generally understood to apply to a mixture of silica sand with a suitable bonding material. In practice there is no sharp line of demarcation between the natural and synthetic mixtures, the latter often containing some natural bond, provided that the basic sand grains are of suitable character. As with any sand, the three constituents to be controlled in any synthetic sand are:

(1) sand grains,
(2) bonding material, and
(3) moisture content.

The selection of a suitable base sand is most important, and is determined, broadly speaking and ignoring economic considerations, by (*a*) the permeability required, (*b*) whether a fine casting finish is necessary, and (*c*) what class of metal is involved, i.e. steel, malleable iron, light or heavy grey iron, or any particular non-ferrous alloy.

Our present knowledge indicates that in assessing the value of a particular sand to form the basis of a synthetic moulding mixture, the following are good characteristics:

(1) A uniform size of grain, i.e., not spread over a large range of grain sizes;

(2) As low a proportion of silt and coarse sand as possible to avoid fitting in of grains with consequent low permeability;

(3) Absence of clays which are easily dehydrated or of low refractoriness;

(4) Freedom from mineral impurities such as mica and alkalis, which lower refractoriness; and, finally,

(5) A subangular-shaped grain, preferably with worn surface, or coated with a film of clay or colloidal mineral substance.

The silica sands given in the following table are some which have proved satisfactory as the basis of synthetic moulding sand mixtures in Britain.

Steel	*Malleable iron*	*Grey iron*	*Light alloys and non-ferrous general*
Leighton Buzzard (coarse and medium), King's Lynn silica, King's Lynn red, Chelford silica, Ryarsh silica, Yorkshire, and Scottish rock sand	Leighton Buzzard (medium and fine), Congleton silica, Erith silica, Chelford silica, and Sea sand	Sea sand, Congleton silica, Redhill F Leighton Buzzard (medium), and Erith silica	Bedford silica, sea sand, Leighton Buzzard, Erith silica, Redhill F silica, New Forest silica, sands, and Ryarsh silica

It is generally inadvisable to use a mixture of two sands unless they are carefully graded and proved to give a satisfactory permeability when mixed. Troubles arising from mixing of unsuitable sands is explained by the "fitting in" theory of Sheehan ("Control in the Core Shop," *I.B.F. Proceedings*, 1939-40), and for this reason the core sand used in a synthetic sand foundry should be selected with a view to its eventual addition to the moulding sand system, and, where possible, the same basic sand should be used for both purposes.

Special considerations such as surface finish, resistance to metal penetration, extra good green bond or plasticity, account for the not infrequent addition of some proportion of natural bonded sand, silica flour, or a fine-grained silica sand such as Ryarsh to synthetic moulding mixtures.

The effect of grain size and uniformity of grading on permeability and strength is evident, but the effect of the surface character of the grain is also considerable.

In use a clean sand grain soon becomes coated with a film of carbon, and dried clay and masses of grains become cemented together. When the dry strength of the cementing film is high, as, for example, when bentonite is used as a bond, it becomes difficult to break down all these pellets in the usual milling time, and in consequence the facing sand tends to become coarse and full of small pellets of hard sand.

The choice of a bonding agent will depend mainly on the class of work and dry-strength requirements. The best plastic bonding clays are the colloidal bentonite clays and the newer blended or prepared clays such as Fulbond. An idea of the relative bonding values of some of these clays is given in the following table of approximate values:

Type of clay	*Green bond value*	*Dry bond value*
Southern bentonite	100	70
Western bentonite	75–80	100
Colbond	50–60	40–50
Fulbond No. 1	75–80	55–60
Fireclay	30–35	25–30
Fulbond No. 2	75	70–80

Examples of typical synthetic sand mixtures are given in Tables 7.7 and 7.9. When starting up with new sand, the full bond is not developed immediately. Not until the sand has been in use for a short time and the grain surfaces have become thoroughly coated does the full plasticity and bonding value become effective. Besides clays, certain organic substances, such as concentrated sulphite lye, dextrin, molasses, or oil may be added in small proportions to synthetic sands, to obtain better dry strength or green strength and counteract the tendency of such sands to dry off and give friable edges and corners to the mould. The use of such materials is, therefore, additional to the mineral bond.

Small additions, of about 0·5 to 1·0 per cent, of wood flour or cereal flour have been found effective in preventing scabbing of the mould face, caused by thermal expansion.

The moisture content of synthetic sands is generally considerably lower than with natural bonded sands, and for green sand work is usually in the region of 3 to 3·5 per cent. The low moisture content and high permeability of these sands accounts for the more rapid drying off of the sand and creates operating difficulties in a mechanized foundry where the sand temperature often rises rapidly in the system and control of a consistent moisture content is not easy. Final moisture adjustment is made at the mill, and should be kept within ± ¼ per cent of the desired value.

Mixing and milling may be either continuous, or by batches, where individual charges are dealt with and a definite proportion of new bonding clay, water, etc., is added. On the continuous mill the amount of milling of the sand is usually limited by the capacity and output of sand required to a very short period, say, 1 to 2 minutes or less, but the same sand may be remilled and used once every hour. Effective distribution of the small bond clay addition is often incomplete in the continuous system, and to improve this the clay may be mixed with a proportion of sand or other additions to increase the bulk added, or in some cases it is practicable to make the addition as a water suspension, or slip, where the consequent increase in moisture content of the sand is not too high.

The advantages and disadvantages of synthetic, as against natural, bonded sand are briefly summarized as follows:

Advantages	*Disadvantages*
(1) Lower cost of sand maintenance and no sand to dump.	(1) Probably high first cost.
(2) Improvement in permeability and lower moisture with less chance of blown or porous castings, chilling, etc.	(2) Drying out gives friability and washes.
(3) Sand easier to work on mass production moulding.	(3) Patching is difficult.
(4) Enables semi-skilled operatives to work machine moulding.	(4) Balling up may give poor finish.
(5) Possible to use up old core sand and reclaimed sand.	(5) Synthetic sand needs more careful control than natural bonded sand.

BLACKINGS, MOULD AND CORE DRESSINGS

A CONSIDERABLE number of materials are used in the foundry to give protection to the mould and core surface against the action of liquid metal, and help produce a smooth, clean skin on the casting, by preventing metal penetration of the mould face. Apart from the usual highly refractory substances which will remain unmelted at the temperature of the molten metal, certain dressings have special properties which fit them for this purpose. Such dressings are generally applied as a thin coating on the prepared sand face by: (1) dusting or rubbing on the dry material; (2) spraying or painting on in the form of a liquid suspension. In some circumstances small proportions of blacking or mineral facings are mixed in with the facing, or core sand, to improve its refractoriness and prevent metal penetration.

The principal materials in use can be classified broadly into two groups: (*a*) carbonaceous materials such as plumbago and blacking, (*b*) refractory

TABLE 7.10

COMPOSITION OF VARIOUS CARBONACEOUS FACING MATERIALS

Material	*Fixed carbon per cent*	*Volatile matter per cent*	*Ash per cent*	*Moisture per cent*	*Sulphur per cent*	*General character*
High-grade Ceylon plumbago	82·0	2·5	15·0	0·5	0·35	Fine silvery flake
Common plumbago	65·0	3·5	30·0	1·0	0·70	Coarser dark flake
High-grade carbon blacking	94·0	3·0	2·0	1·0	1·0	Fine, soft and dark, 100 per cent through 90 mesh
Common coke blacking	84·0	2·3	12·0	1·5	1·60	Grey-black, harsh feel
Anthracite powder	89·0	7·0	3·5	0·5	0·25	Fine lustrous black. Rather harsh feel
Bituminous coal dust	56·8	35·0	6·6	1·5	1·40	Soft, rather dusty. Varies in grade

mineral powders such as zircon flour, talc and china clay. Most of these materials are available in various grades according to purity and fineness. In addition the proprietary mould and core dressings often consist of a mixture of two or more ingredients, the proportions being varied to suit a particular application. Thus, plumbago may be mixed with french chalk, bone ash, or powdered clay for non-ferrous work and with silica flour or carbon blacking for iron or steel founding.

The composition of a number of typical carbonaceous facing materials is given in Table 7.10. Probably the most important of these is graphite (plumbago). Graphite is a mineral form of carbon widely distributed in various parts of the world. Important deposits occur in Ceylon and other parts of India, in Siberia, Canada, and to a lesser extent in Europe (Bavaria and Sweden). It occurs in two principal forms, crystalline and amorphous. The crystalline form, usually known as plumbago, has a characteristic structure breaking down into small flat scales, or thin plates, when crushed. This powdered greyish-black plumbago has a silvery lustre and a soft soapy or slippery feel. The purest qualities contain from 75 to

90 per cent carbon, the remainder being mineral matter, silica, iron oxide, etc. It burns very slowly when heated in air and is difficult to ignite. In the absence of oxygen, plumbago undergoes no change even at fairly high temperatures. It is a good conductor of heat and electricity, and on account of its flaky nature has excellent covering power.

Apart from its uses in the foundry it finds many applications in furnace work and in the manufacture of melting crucibles on account of its refractoriness and thermal conductivity. It is used both for ferrous and non-ferrous castings, producing a smooth surface to the metal solidifying against it and preventing fusion of the liquid metal and sand at the mould or core surface. Flake plumbago itself does not adhere well to a sand surface, although it can be rubbed, or sleeked, in with flat tools. As with other types of non-adhesive substances, it is usual to add a proportion of some type of binder such as clay, silicate of soda, core gum, molasses, or concentrated sulphite lye when making up the coating mixture, to give the necessary grip, or strength, of bond. Plumbago is often added to other mineral dressings to overcome any tendency for fusion of the coating to the casting and to increase the covering power of the dressing. It is also applied, in colloidal form, as a dressing to metal dies and cores used in permanent mould casting. Typical examples of mixtures containing plumbago are given later. Amorphous or non-crystalline forms of carbon include lamp black, charcoal, gas carbon, and coke, as well as natural deposits of soft black graphite.

Coke, coke breeze, and coal dust from selected grades of coal form the main basis of the blackings in common use in most iron foundries. Coal of low ash and volatile matter, such as anthracite, is used and the fixed carbon content of these blackings is frequently as high as 90 per cent. Sulphur compounds are always present to some extent and may be as high as 1·5 to 2·0 per cent. A typical grading and proximate analysis of a coke blacking is given in Table 7.11. Coke dust and pulverized hard coal tend to be gritty and abrasive unless very finely ground, and when used dry are

TABLE 7.11

PULVERIZED COKE BLACKING

Proximate analysis per cent		*Sieve test per cent weight*
Moisture	1·5	Passes through 60 mesh = 100·0
Volatile matter	3·0	Passes through 90 mesh = 99·5
Mineral ash	7·0	Passes through 120 mesh = 98·0
Fixed carbon	87·0	Passes through 200 mesh = 90·0
Sulphur	1·6	

usually mixed with a proportion of talc or soap-stone powder, as in the case of bath mould dressings.

Black Wash, i.e., blacking mixed with water, usually has an addition of a bonding agent such as colloidal clay, fireclay, dextrin, molasses, etc., as in the case of plumbago, in order to prevent the film of blacking rubbing off the mould or core too easily after drying and during subsequent handling. The addition of a colloidal clay such as bentonite also helps to keep the carbonaceous matter in suspension for a time after mixing the black wash. Coke has a specific gravity of approximately 1·3 and tends to settle in water fairly rapidly, even when very finely ground, and consequently needs constant stirring during use, or preferably some mechanical mixing device if large quantities are used.

Coal Dust is used in very large quantities for green sand moulding, as discussed in the previous section on sands, as a direct addition to the moulding system. For this purpose the bituminous type of coal is selected with a high percentage of volatile matter, whilst for wet and dry application as a facing, hard coal or anthracite with a fixed carbon of about 85 to 90 per cent and a considerably higher ignition temperature is used. The volatile matter from the coal dust in the mould is evolved under the heat from the metal poured and forms a protective gas atmosphere at the mould face. The coal dust should be of such fineness that it will readily gasify under the heat of the cast metal but not so rapidly as to burn all away before the metal has set in the mould. For this reason different grades and fineness of coal dust are used according to the average metal thickness being cast, and it is also common practice to increase the amount added in proportion to the increased section thickness of the castings. Figures from a report on the use of coal dust are given in Table 7.12. In green sand iron moulding, the addition of from 5 to 10 per cent by volume of coal dust to the facing mixture is common practice for batch mixing, whilst in continuous sand systems the addition may be 0·1 to 0·5 per cent of the sand which passes into the mixers. An excessive use of coal dust often results in mapping, rat tailing or crazing of the surface of the casting, rounding of sharp edges, and general poor reproduction of detail, whilst the sand is overloaded with carbonaceous matter which may cause balling up of the sand and pellet formation.

Coal dust gives rise to increased green and dry strength of the sand, but this effect is a gradual process during the repeated use of the sand and not an immediate result of adding coal dust to a new sand and milling with the required tempering water. Briefly, the effect of coal dust in the mould is:

(1) It increases the refractoriness of the sand by depositing carbon and decomposition products of coal on the sand grains;

(2) It produces gases at the mould face during casting, so preventing

TABLE 7.12
COAL DUST

Average metal thickness—in.	*Fineness (sieve test) of coal dust*	*Grade*
(1) Less than $\frac{1}{8}$	100 per cent through 240 mesh	Special superfine
(2) $\frac{1}{8}$–$\frac{1}{4}$	100 per cent through 200 mesh	Superfine
(3) $\frac{1}{4}$–$\frac{1}{2}$	85 per cent through 200 mesh, 15 per cent through 100 mesh	Fine
(4) $\frac{1}{2}$–1	50 per cent through 30 mesh and on 100 mesh, 50 per cent through 100 mesh and on 150 mesh	Fine medium
(5) 1–2	25 per cent on 30 mesh, 50 per cent through 30 mesh and on 100 mesh, 25 per cent through 100 mesh and on 150 mesh	Coarse medium
(6) Greater than 2	50 per cent on 30 mesh, 50 per cent through 30 mesh and on 100 mesh	Coarse

(By courtesy of the British Cast Iron Research Association)

direct contact between the molten iron and the sand or clay particles;

(3) It produces a reducing atmosphere in the mould cavity as it fills with molten metal;

(4) The bond and dry strength of the sand are improved;

(5) The presence of coke particles between the sand grains allows for some expansion of the rammed mass of sand without cracking or bulging and maintains permeability in the mould.

As an alternative to coal dust, pitch powder or mineral gilsonite is sometimes used, with the advantages that only about one-third of the quantity is required compared with the amount of coal dust normally used and very much less coke or burnt coal dust accumulates in the system sand.

Mineral Powders, used in core and mould dressings, may be divided into two groups: (1) those which have a soft, slippery feel and a flaky or scale-like shape of particle; and (2) those which consist essentially of fine powdered minerals of a highly refractory character.

In the first group are talc and soapstone, names given to certain varieties of the mineral steatite (hydrated magnesium silicate).

Talc, commonly known as french chalk, occurs in the form of small flakes or flat crystals which break down in thin sheets as in the case of plumbago. It is supplied in various grades according to fineness and purity, and should be pure white.

Soapstone is a white to greenish-white powder, very similar in composition to talc and also has a smooth, slippery feel. Both have comparatively low fusion temperatures and are, therefore, used mainly in non-ferrous foundry work or for dry application where a smooth polished surface is required, and blacking is added to provide the real refractory part of the dressing.

Amongst the purely refractory mineral powders silica flour is still used to a limited extent as the basis of wet dressings for cores and moulds in the steel foundry, although it has been largely replaced by the more refractory and considerably more expensive zircon flour. Silica flour is produced by fine grinding of pure quartzite rock and can be obtained in various degrees of fineness down to 300 mesh or finer. For most purposes, a 200-mesh product is satisfactory. A typical Welsh silica flour (SiO_2 98·5 per cent) will have a softening point of over 1,700 deg. C. Zircon flour (zirconium silicate $Zr\ SiO_3$), obtained similarly by fine grinding of zircon sand, has a softening point of over 2,000 deg. C. It is used extensively as a core and mould wash for heavy and alloy steel castings (see Table 7.15).

Other highly refractory minerals prepared synthetically and used in certain types of dressings include alumina, ground chamotte and ground molochite (pre-fired china clay). Less refractory materials employed in the non-ferrous foundry may also contain tripoli powder, kieselguhr, or bone ash with varying proportions of plumbago. These mineral powders have no natural bond and therefore when being applied in the form of a water paint or wash are usually mixed with a certain proportion of clay—which may be a refractory plastic clay such as china clay, ball clay or, more frequently, bentonite.

Organic Substances are commonly made use of as bonding agents for facing materials which, as previously mentioned, have little or no natural adhesive properties. Various types of soluble starch, dextrin, molasses and sugar, which possess good adhesive properties and contain a high proportion of carbonaceous matter, are mixed in with the powdered dressing or added as a water solution when preparing the wet mixing for use. Most of the examples of mixed dressings given later include a proportion of one or other of these substances which, as the film of blacking or core dressing dries off, hardens and holds the particles of graphite, zircon or chalk, etc., firmly in place. Apart from their function as binders for facing minerals, such substances as core gum, molasses, concentrated sulphite lye, sodium silicate, vegetable oils and various types of natural and synthetic resin may be used alone as hardening agents on the surface of sand moulds and cores.

Where a waterproof finish or moisture-resisting surface is required, particularly, a thin spray of linseed oil and a dusting with resin or pitch, either dry or in solution, is quite effective. After coating, the warm mould or core should be heated at about 150 deg. C. for a sufficient time to thoroughly dry and harden the surface.

An advantage of using this type of soluble ingredient alone is that surface permeability to gases is not appreciably affected, as distinct from many of the paints and washes which produce an almost impermeable film. On the other hand, such substances usually evolve considerable gas or vapour when subjected to strong heat, and in some castings this is a serious disadvantage.

In preparing dressings for permanent moulds (such as billet or ingot moulds and dies for gravity casting of light alloys), a bonding agent which does not decompose readily under heat is required. Such a material is waterglass, or commercial silicate of soda, which has strongly adhesive properties for bonding fine mineral powders on to a metal surface and on heating strongly forms a glass which softens gradually at a red heat. Waterglass can also be used as a permanent bond with silica sand or crushed refractory to produce core-drier shells or blocks which will withstand repeated oven heatings without crumbling. Two grades of silicate, neutral and alkaline, are available in various concentrations, as well as in dry powder form. The neutral grade is preferred for foundry dressings.

APPLICATION AND PREPARATION OF MIXTURES

Blackings may be applied wet or dry, in the form of powder, stiff pastes, or thin creams. In green sand moulding, dry blacking may be dusted on with a bag and the surface sleeked with a flat tool. It is more common practice to sleek the face of a green sand mould with water, or a thin black wash by means of brushes or soft rag swabs, followed by a final smoothing with a suitable tool. This wetting of the surface and smoothing produces a better finish on the mould, compacting it and increasing the surface strength.

In certain green-sand work, as, for example, the production of cast iron baths as carried on in the Falkirk district, the whole surface of the mould is hand dressed with a special bath mould dressing. This powdered dressing is spread over the surface and rubbed in with a piece of fur, or the palm of the hand, until a smooth, polished finish is obtained. Excess blacking is lightly dusted off before closing the mould. The special dressings for this work usually contain a considerable proportion of talc.

Wet Application of blackings and mould, or core, dressings may be made by spraying, swabbing, brushing on, or by dipping the job into the black wash. In preparing the mixture, the powdered material is added with constant stirring to sufficient water to produce a cream of the required consistency, the thickness varying according to the method of application of the dressing. The recommendations given in Table 7.13 for wet blacking mixtures have appeared in papers* to the Institute of British Foundrymen by J. J. Sheehan and F. Hudson.

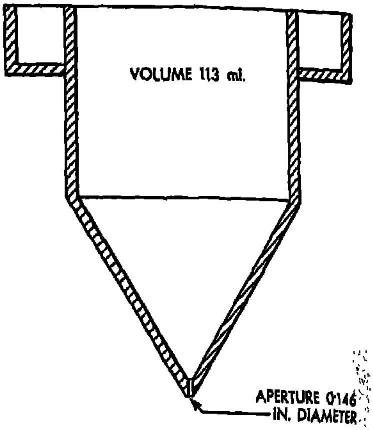


FIG. 7.26. *Sectional view of simple viscometer suitable for control of blacking-wash thickness.*

Reference has already been made to the necessity for constant agitation of black wash in order to obtain a uniform coating, and a simple means of checking the consistency of a batch is by means of a density determination with a suitable hydrometer, or by testing its viscosity with a simple form of paint viscometer (see Fig. 7.26).

In the case of mineral dressings containing clay or bentonite, the best procedure to obtain a smooth cream is to add the powder to a limited amount of hot water, stir vigorously until the thick cream becomes smooth and free from lumps and then dilute with cold water to the required degree for use. Core gum, or core compound, can also be rapidly dissolved in hot water. The mixture should normally be left to stand for several hours, and preferably overnight, before being used to ensure complete breakdown and wetting of any small lumps of powder or binder which would give a lumpy coating. The addition of a very small percentage of a wetting agent, such as "Teepol," in the water used will assist in speeding up mixing.

In applying wet dressings, spraying is the most efficient method of producing an even coating. Hand application with brush, or swab, is liable to break away the wet surface unless due care is taken. For this reason a single coat of the required thickness is best, and if it is necessary to give a second or third coat, it should not be applied until the first coat has dried and hardened. It is difficult to give any actual limiting values for

TABLE 7.13
RECOMMENDATIONS FOR WET BLACKING MIXTURES

Method of application	*Thickness of blacking mixture*	
	Viscosity (Sheehan)	*Specific gravity (Hudson)*
By spray or swabbing	46	1·21–1·24=25/28°Be
By brush application	—	1·26–1·28=30/32
By dipping	54	1·35–1·38=38/40

the thickness of coating to be applied, but the details of mixing proportions given in the text will enable a satisfactory coating to be obtained, provided that the right consistency is maintained. Plumbago dressings are sometimes used in the form of a stiff paste to rub on the face of a core, or mould, by hand. The paste is produced by kneading in molasses-dextrin-water cream or clay water.

BLACKINGS AND FACINGS USED IN THE IRON FOUNDRY

For *green sand* moulds plain carbonaceous blackings are generally used, with additions of clay, molasses, or core gum as binder when used in the form of black wash. If a wet blacking is used on a large mould it is usually skin-hardened by passing the flame of a gas torch or blow-lamp quickly backwards and forwards over the surface until it is dry. Where a particularly good surface finish is required a proportion of fine plumbago is added, plumbago being considerably more expensive than most blackings, its use is naturally restricted.

A small proportion of common salt is sometimes added to black wash to assist in bonding the blacking to the mould surface and is present in some proprietary dressings. As a guide, an addition of 1 oz. of salt per quart of water will be found effective. Foundry blackings and plumbago should be purchased to definite limits of purity and fineness according to requirements. The figures given in Table 7.14 are an example of a specification for high-grade blacking and plumbago for iron foundry use.

For dry-sand moulds and cores, a wet black wash is generally applied by spraying, or painting, on to the warm surface as removed from the drying stove; the coated mould or core is then given a final drying in a stove, or warm room, kept for the purpose at a temperature somewhat above 100 deg. F., before being put down for casting. In the mass produc-

TABLE 7.14
FOUNDRY HIGH-GRADE BLACKING

Proximate analysis	(*A*) *Carbonaceous blacking per cent*	(*B*) *Foundry plumbago per cent*
Moisture	3·0 max.	1·0 max.
Volatile matter	7·0 max.	3·0 max.
Ash	15·0 max.	Difference
Fixed carbon	Difference	80·0 min.
Grading	98 per cent passing 100 mesh B.S.S.	95 per cent passing 100 mesh B.S.S.
Character	Must be free from coarse particles	Must be a natural flake graphite

tion of small and medium cores, etc., in large quantities, mechanical dipping in tanks of black wash is sometimes used, and conveyors carry the work through continuous drying ovens.

Dressings for CO_2 Process. Water-base dressings are not generally successful in CO_2 process cores or moulds and instead "self-firing" or so-called "flash" dressings, in which isopropyl alcohol or spirit is used as the vehicle, have been developed. The mineral base is usually plumbago, blacking, talc or mica mixtures bonded with an alcohol-soluble gum or resin, just sufficient to prevent the dressing rubbing off the sand face after the spirit has burnt off or evaporated.

FACINGS USED IN THE STEEL FOUNDRY

The extremely high temperature at which liquid steel enters the mould necessitates the use of exceptionally refractory dressings in order to reduce fettling costs and give a clean break-away of sand from the casting. Apart from plumbago, which is only used to a limited extent, refractory fire-clays, ground chamotte and zircon flour are the principal materials used. Whilst theoretically the softening point of such dressings is seldom reached, and then only in the surface layer against the metal, in practice there is usually some sintering, or partial fusion, between the fine particles of siliceous material, no doubt due to the fluxing action of iron oxide at the mould face.

Provided this fusing action is not accompanied by penetration of the mould face by liquid steel, thus forming a mass of sand grains surrounded by metal most difficult to remove, the sintered mould face will fall away in patches as the casting cools and contracts, leaving the cast surface relatively clean. The action of the dressing is, therefore, largely to prevent any such penetration of liquid steel by closing up the surface structure of the mould and strengthening it against the washing action of the metal. Two examples of typical mixtures in use for painting steel moulds and cores are given in Table 7.15. In preparing these mixtures for use, the dry ingredients should be well mixed together and then added gradually to a portion of the water heated to near boiling point, diluting as required.

TABLE 7.15
STEEL FACING MIXTURES

(1)		(2)	
Zircon flour (200 mesh)	80 lb.	Chamotte (calcined and ground, 200 mesh)	3 lb.
Bentonite	15 lb.	China clay	1 lb.
Dextrin	5 lb.	Dextrin or Core gum	¼ lb.
Water (milled in)	4–5 gal.	Water	1 gal.

FACINGS USED IN THE NON-FERROUS FOUNDRY

Small castings in brass and bronze are usually cast in green sand and seldom given any special surface coating. For more important work, such as pressure castings for hydraulic and steam fittings in phosphor-bronze and high-tensile bronzes made in dry sand moulds, dressings based on plumbago-talc mixtures are in fairly general use. As a binder for these minerals some form of sugar, or other soluble adhesive such as starch, gum and, more rarely, silicate of soda, are used. Examples of mixtures used as dressings for various non-ferrous alloys are given in Table 7.16. Here, again, one of the main purposes of these dressings is to prevent metal penetration of the sand surface of core or mould since such alloys as phosphor-bronze are particularly searching and wet the mould face intimately. For this reason a fine-grained moulding sand is used, and low permeability restricts the use of coal dust or other volatile matter in the facing sand.

It should be emphasized that a good dressing can be spoilt by bad application. In order to give a clean "strip" and smooth casting finish, the coating or dressing must be applied as a continuous layer of uniform thickness all over the core or mould surface. It must not crack or "spall" away from the sand under the heat from metal entering the mould, or wash off the surface. A dressing applied too thickly will crack and flake away on drying, as will a dressing which is too weakly bonded. Spraying with a fairly thin dressing, with ample air pressure, followed by thorough but slow drying will usually give the best results.

TABLE 7.16

NON-FERROUS FACING MIXTURES

(1) *Examples of dressing used for phosphor-bronze and high melting point non-ferrous alloys:*		
Best fine plumbago	=2 lb.	Mix with ½ gal. hot water and dilute further if required for spraying.
China clay	=1 lb.	
Molasses	=¾ lb.	
(2) *Dressing for general brass and bronze castings:*		
Fine silvery plumbago	1 lb.	Add to approximately 1 gal. of water for use.
Best white talc	3 lb.	
Molasses	1 lb.	
(3) *For light alloy castings:*		
Best white talc	2 lb.	Make into thin cream with water for spraying on.
Whitening	1 lb.	
Molasses	1 lb.	

Chapter 8

MOULDS AND HOW THEY ARE MADE

THERE has been considerable technical progress in the moulding shop, as in other foundry departments, during the past twenty years. In particular, plant and equipment have been designed to meet almost any moulding-shop requirement which will mechanically take the "hard-labour" routine work out of the job (see Fig. 8.1). In days gone by, foundry labour was easy to replace and candidates for moulding and its associated tasks were plentiful. "Brawn" as well as "brains" was an advantage in founding and there was room for most applicants in the moulding shop, where hard work, smoke and drab conditions were then accepted as apparently inseparable from the art of making castings. The extent of a man's practical moulding experience, often acquired by trial and error, was easily gauged in the fettling shops, where castings—the

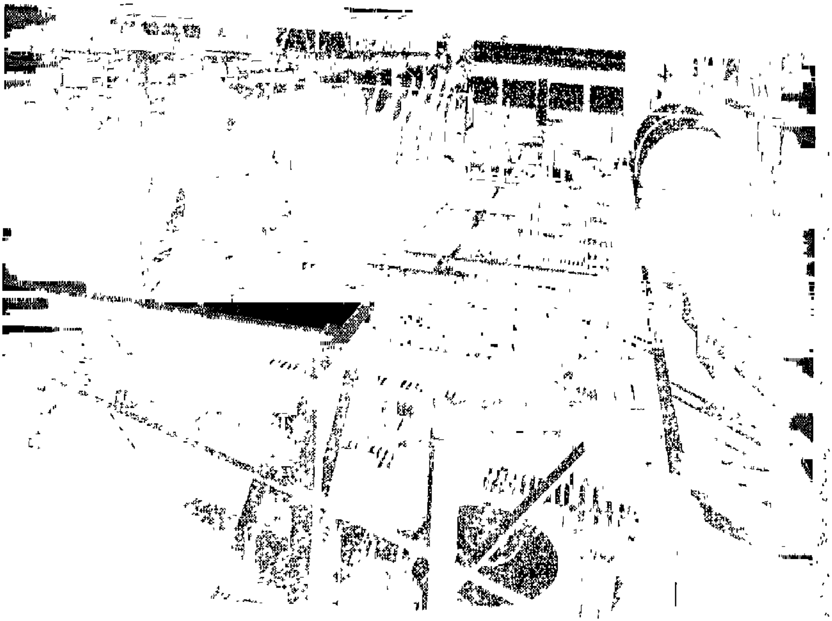


FIG. 8.1. *General view of a mechanized moulding shop.*

products of his skill—came to be dressed and finished ready for despatch.

Conditions are very different today. New processes and materials have been especially developed to remove most of the hazards of production and uncertainty as to the quality of the ultimate casting which were accepted in the past as part of the job. Moulding sand, usually quarried locally, was "just moulding sand" to the itinerant moulder and its own particular vices or virtues were found out the hard way—in practice. It seems incredible, in these times of close control and analysis of raw materials and the like, that the four main materials in use for centuries of making moulds and cores were quarried sand, water, coal-dust and manure. These basic materials were mixed by individual moulders according to their own experience or the shop tradition and the results, namely, the castings, were entirely the moulders' responsibility.

There are still many moulding shops where highly-skilled moulders spend much of their time in ancillary jobs more suited to labourers. They knock-out the previous day's castings, mix sand, fetch cores and pour their own moulds. Yet it has long been recommended by the various advisory committees concerned with problems arising from shortage of moulders that any method or equipment which would permit skilled moulders to spend their whole time at moulding should be adopted. Also, all services to the individual moulding stations should be provided by other than skilled craftsmen or by mechanized supply systems.

Nowadays, sand-mixing control, the measurement of bond-strength and permeability, are almost universally expected in moulding shops. As a result of the supervision imposed, castings of quality to any stipulated requirements can be put in hand with confidence, and specifications followed with assurance. Along with modern synthetic-sand mixtures and other improved foundry materials, there is technical control imposed in all directions, from specifying the grain size of a sand to the removal of accumulated silt. Sand and metal mixtures to any given standard can be consistently repeated. Oil, powder or cream binders for cores or moulds are regularly used to provide a practically "fool-proof" moulding or core sand which has a remarkably high resistance to penetration of high-melting-point metals.

Notwithstanding all the modern improvements in materials, working conditions, etc., the best type of "old-time," widely experienced moulder who could take on any class of job is growing more scarce, and many ingenious innovations have been introduced to overcome this shortage of skilled men. From high-class moulding machines, for instance, moulds can be produced with almost automatic precision. However, this chapter is mostly concerned with the hand production of moulds, for it is from that basic craft that the mechanical devices of mould production have stemmed.

The examples chosen for illustration purposes are mainly typical of patterns moulded "loose."

Foundry nomenclature is not the same in all districts; however, a "cope" is always a top half-mould and a "drag" is a bottom half. Of course, for all castings produced by any of the sand-moulding processes, some form of pattern or sweep-board is necessary; other essential tools and equipment will be described later. Moulding procedures can best be clarified by reference to the illustrations included for each operation.

We shall begin by considering the smaller type of patterns intended for one-operator, bench-moulding routine. Fig. 8.2 shows a composite bench-moulding unit, together with most of the tools and other items associated with this type of mould production, though not all of these are usual at any one station. Some of the moulders' tools are, of course, in common use for all sand-moulding processes.

Bench and floor-moulding stations (Fig. 8.2), where circumstances permit, can be positioned directly under or near hoppers for supplying moulding sand, as at A and B. Of the hoppers illustrated, A has standard clam-shell doors and B provides a hand feed. As an alternative to overhead hoppers, a floor-bin type, C, may be provided, which can be filled from a bulk sand supply as required. Any of these methods of supplying sand will permit maximum time to be spent by the moulder at actual moulding. The unit type of bulk-sand supply is not suited to all moulding jobs and very often special mixings of sand are delivered to certain stations. In addition, facing sand—to be packed in the mould portion closest to the pattern—can also be supplied to the moulder in handy skips (as at D) or other similar containers.

MAKING SIMPLE MOULDS

To introduce other moulders' equipment and tools, the step-by-step procedure in moulding a gear-wheel "blank" casting will now be described. The gear-wheel pattern E (Fig. 8.2) is shown as a "flat-back" type of job, and is first placed face down on the ramming-up board F. A moulding-box section or part is laid over the pattern, resting on the pattern board. In Fig. 8.3 is shown the first sand layer or course. The number of these ramming courses required depends on the depth of the pattern and the box. Sand is put into the moulding-box to approximately 4 to 5 in. in depth, and is levelled out to leave the pattern clear. The short hand-rammer, G, is then used with a firm, up-and-down stroke—and in a slowly progressive clockwise direction—to ram the course (layer) of sand evenly. The rammer should be so controlled as to ram the sand to within one inch from the pattern face, as shown. About two circuits of the box will usually serve to ram each course to an even density or hardness.

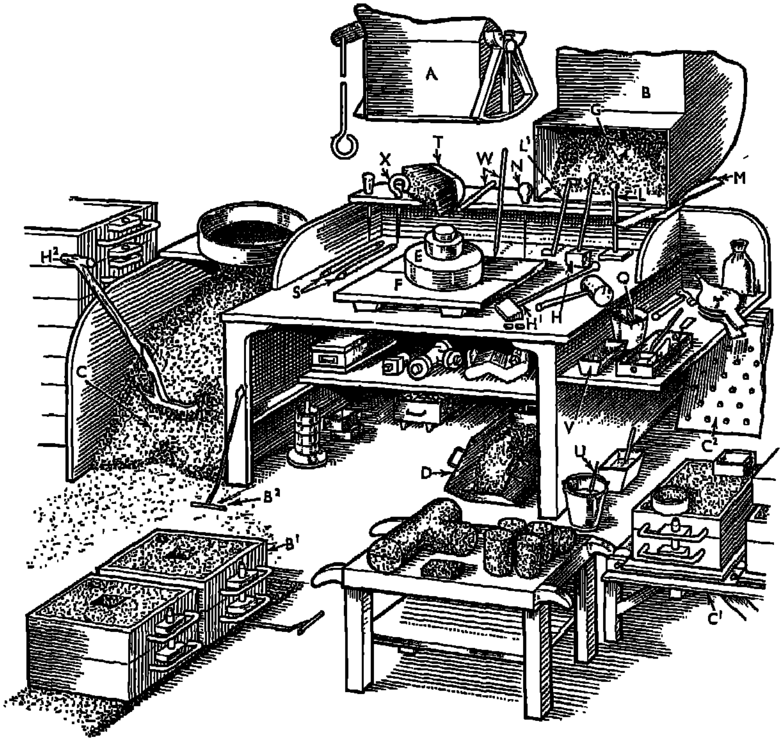


FIG. 8.2. *Layout of a bench moulder's working place.*

The number of the ramming circuits required, and also the hardness imparted to each sand course, is decided by the size and shape of the rammer end, H, a somewhat rounded "bull-nose" being preferable to the sharper cutting edge of type H1. Individual preference and ramming experience will soon indicate the most suitable shape and weight for various jobs. Where a shovel is used to fill the moulding box with sand, moulders will often up-end this and use the crutch (handle) end, H2, for the speedy hand-ramming of some of the sand courses. After evenly ramming the first course, more sand is put into the box and levelled out as before, always leaving the pattern uncovered as long as the pattern depth and shape will permit (Fig. 8.4).

The last ramming course is piled up above the moulding-box edge, as shown in Fig. 8.5 at J, deep enough to permit a hard flat-ramming course to depress the sand to approximately ¼ in. or so above the box edge, K. The square, round, or rectangular-shaped type of flat rammer, L, employed for this should be quite "weighty"—a rammer 4 × 2½ × ¾ in.

thick is a useful size for one-hand moulding in small boxes. After hard flat-ramming, the surplus sand remaining above the box edge is removed with the strickle bar, M, shown in Fig. 8.6.

When producing castings for engineering applications made in ordinary undried moulding sand (green sand), it is both customary and advisable to use a wire (N) for pricking in vent holes in the body of the mould to provide an easy exit for the gas and steam pressure which is rapidly generated later on when molten metal is poured into the mould. This rapid expansion of gas, or steam pressure, if not released freely through vent holes, will force its way into the molten metal and bubble through runner, riser or feeders. Agitation of the metal may continue until the gas pressure is spent or the metal is set and a defective casting is the result.

After strickling and venting, it is advisable next to cramp and wedge the box-part handles and ramming-up board together for rolling over, as shown at O, Fig. 8.6. With many patterns, however, a rammed-up mould and pattern can be lifted directly off the table (or board) and rolled over without cramping, using the edge of the moulding-bench as a pivot. After rolling this first half-mould so that the pattern face is uppermost (Fig. 8.7), the sand joint, P, is smoothed over with the trowel, and parting-powder, Q, is then lightly dusted on to the joint face; this powder is essential for later separation of the top and bottom half-moulds. The parting medium nowadays is almost invariably a proprietary non-silica waterproof powder. It is shaken on from an open-weave linen bag.

Continuing the operations, surplus parting sand is next blown off the pattern, R, before putting the second (top) half moulding-box into position (Fig. 8.8); this top-half mould is then rammed up, using one or two courses of sand. "Loose" (separate) box-pins, S, are employed in this case to locate one half-box on the other and to preserve alignment when re-assembling. In fact, with first-class, double-lug, rolled-steel moulding boxes, the "loose-pin" system has many advantages for loose-pattern moulding. In other cases, however, paired single-lug moulding boxes with fixed pins and bushed holes (as shown inset, S1 in Fig. 8.8) are employed.

PATTERN WITHDRAWAL

Fig. 8.9 shows the complete gear-blank mould with the top-half removed. Surplus parting sand is brushed off (as at T); then sand at the edge of the pattern is carefully "damped" by squeezing the contents of the water brush, U, through the finger tips in a controlled trickle following the pattern edge—and approximately one inch away from the actual pattern (as at V).

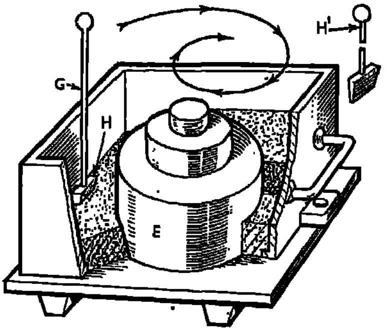


FIG. 8.3

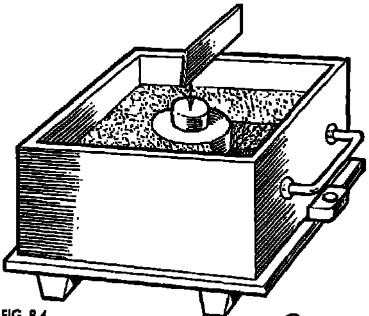


FIG. 8.4

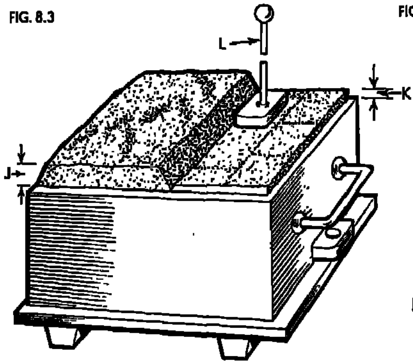


FIG. 8.5

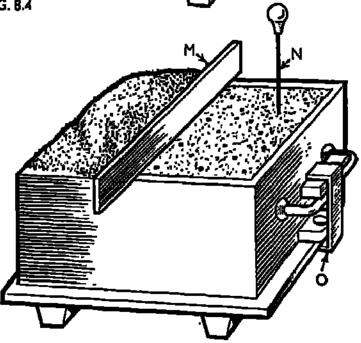


FIG. 8.6

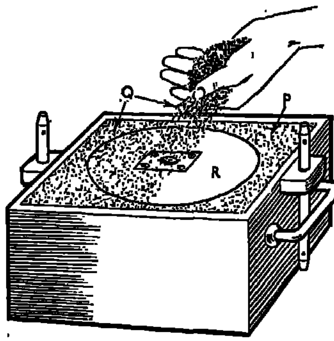


FIG. 8.7

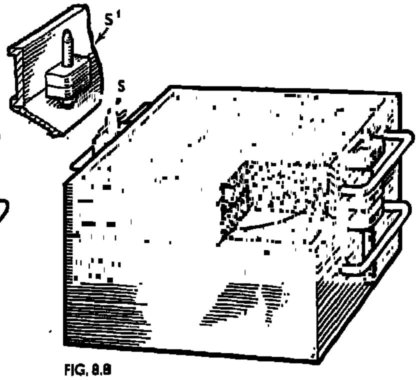


FIG. 8.8

With most patterns, it is necessary to loosen the grip of the sand on the pattern faces and also to provide a small clearance for pattern withdrawal. This is done with the striker and rapping bar, W, Fig. 8.10, the latter fitting into a rapping hole provided in the top face of the pattern. After an even rapping, a lifting screw is inserted centrally to provide a balanced lift as the pattern is drawn out of the mould, as in Fig. 8.11.

When pouring molten metal into moulds to produce castings, it is important to have full control of the flow of metal into the spaces left by the withdrawal of the pattern. This is done—in the case of the gear-wheel blank mould—by cutting an ingate, Y, in the bottom part (Fig. 8.12) of a suitable area and in such a position as to register (when the half moulds are assembled) below the "top-bar" inlet, Z, cut into the

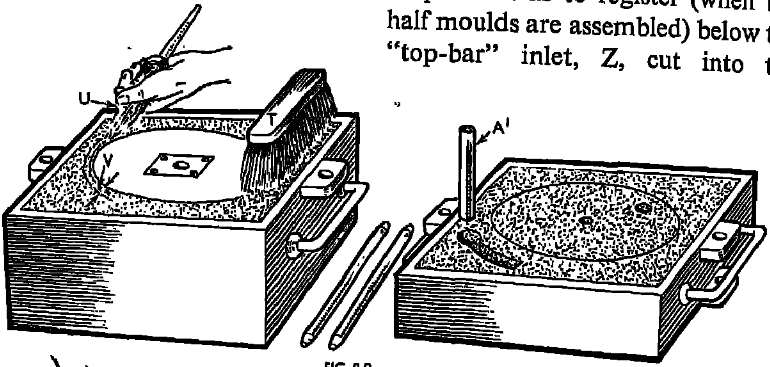


FIG. 8.9

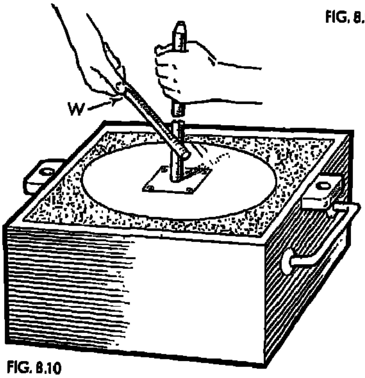


FIG. 8.10

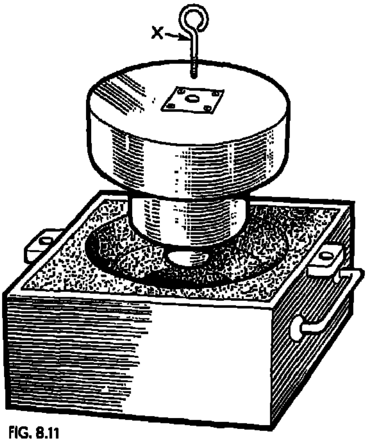


FIG. 8.11

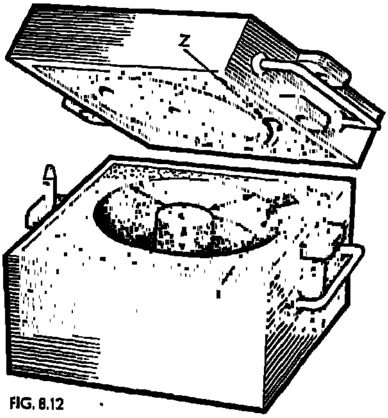


FIG. 8.12

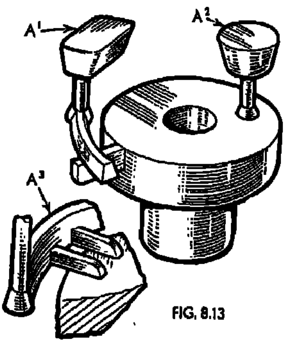


FIG. 8.13

top-part of the mould. This "bar" is connected to the "downgate," A1, which, in turn, leads from the runner-box or bush at its corner (or edge), the purpose being to supply a clean head of metal when pouring.

The downgate for shallow moulds is usually formed by pushing through the rammed half-mould a thin-walled tube (A1, Fig. 8.9) of suitable diameter. The majority of loose-pattern moulders use this almost direct runner-system; it is simple to cut in a mould, but is not necessarily the best means for producing "clean" castings. (Several alternative types of runners are set out in Fig. 8.34.) Often a flow-off or overflow is provided to indicate to what depth a mould is filled with molten metal or to the limit the depth to which it can be filled. Sometimes when these serve as exits from a mould or prevent entrapment of air in a mould pocket, they are termed "risers" or "whistlers." Their effect in "feeding" a casting is only temporary because immediately the "neck" is set, the molten metal in a riser is cut off from the casting and the latter continues to shrink until the whole body of metal is solid. Fig. 8.13 shows the gear-wheel casting with details of the runner at A1, and the riser, at A2. Yet another type of runner is shown at A3.

Quite often, when making castings of considerable thickness and of metals which shrink on solidification (by far the vast majority of metals), substantial feeder heads, blocks or side-heads have to be used to provide a reservoir of molten metal for replenishing the casting as it shrinks. It is necessary for such heads to remain molten until the casting itself is solidified. Fig. 8.39 shows a few of the feeder heads in popular use. Depending again on the type of metal being cast, i.e., whether it has a high liquid-shrinkage (such as steel) or low shrinkage (common cast iron), the ratio of the weight of a casting to that of the extra metal provided to "feed" it can vary considerably. The percentage of feed metal, however, can be considerably reduced by using an exothermic (heat-producing) powder covering developed for the purpose of keeping small quantities of feed metal "alive," that is, molten. Only while a feeder head remains molten can it continue to do its job.

As each loose-pattern mould is cored up and closed, it is routine in many moulding shops to put these down (in a row) on to a level shallow sand-bed (B1, Fig. 8.2). They can be cramped (or weighted) and bushed up individually (or altogether) just before pouring. It is quite usual to vent the sand bed under the bottom mould-face and B2 of Fig. 8.2 shows a $\frac{5}{16}$-in. diameter plum-ended cranked vent wire used for that purpose. With this method of "floor-banking" of moulds awaiting pouring, it is necessary to allow adequate floor-space for each moulder's production.

In many foundries, on repetition work especially, the floor-bank system is replaced by mould storage on roller or pallet conveyors, which first transport moulds to a pouring point and thence to a specially-designed knock-out station. Even in jobbing, i.e., small-quantity production, short lengths of roller conveyor (Fig. 8.2, C1) can be used to advantage. In these cases, perforated mould plates or boards (C2) are placed under each mould. Castings produced from moulds so conveyed and cast up by an expert pourer (perhaps, from a bulk supply of metal employing the type of one-man ladle shown in Figs. 8.35 and 8.36) are often produced faster and more economically than when each moulder pours his own moulds. Also, the quality of the castings produced is usually improved.

SPLIT-PATTERN MOULDING

Patterns split into halves provide much of the work in loose-pattern moulding (Figs. 8.14–8.19). For these, ramming procedure for the bottom-half (Fig. 8.14) and other detailed instructions as set out for the flat-back patterns also apply. Fig. 8.15 shows the top-half box-part of such a mould in place and rammed up and incorporating the top-half of the pattern as shown at A, Fig. 8.14. For half-patterns which are likely to fall out of the rammed top-half mould when this is lifted off, the lifting screw (B, Fig. 8.15) may be inserted into the pattern before ramming up this half-box; the ½-in. diameter rod and wedges (C) being arranged so as to hold the pattern in place after strickling off. Downgate pegs (as shown at D, Fig. 8.15), rammed in position when making the mould, are preferable to the use of the tube type of downgate cutter for deep box-parts.

Fig. 8.16 shows the top half-mould lifted off and the accessories employed; the screwhole, E, is made good with sand before the box is laid down, face uppermost. For the lighter types of patterns which are likely to fall out, a slotted wedge (as at F) can be used with advantage. Before drawing such patterns out of the mould (Fig. 8.17), the position of the lifting screws, G, should be so fixed as to provide an even balance. Runner inlets, H, to register with the top inlet-bar and downgate are cut in before cores are inserted into the mould.

For placing body cores which are too heavy for finger-tip handling, a one-piece cord or tape sling support (Fig. 8.18) can be employed. In many cases, however, cores are put into such moulds in halves, as shown in Fig. 8.19. Here, it is advisable to rub together the core joint-faces, J, once or twice to make a close joint and prevent molten metal when poured from "flashing" into any slit between the half-cores and thus, possibly, plugging the core-vent outlet, K. When the mould is poured, metal must also be kept out of the vents at the ends of the cores. The reason why all core vents must be kept open is to permit the expanded core gases, generated by the heat, to disperse freely to atmosphere, as at L in Fig. 8.19 (and L1 and L2 in Fig. 8.21, which shows the cored-up mould). Fig. 8.20,

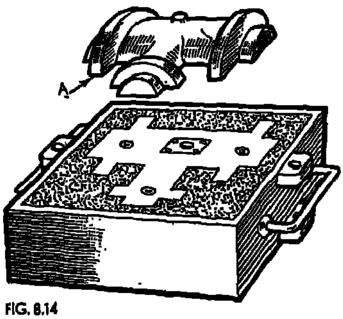


FIG. 8.14

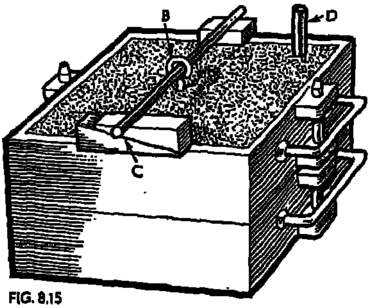


FIG. 8.15

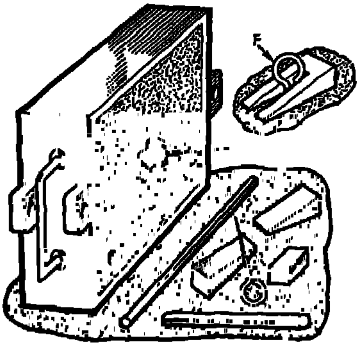


FIG. 8.16

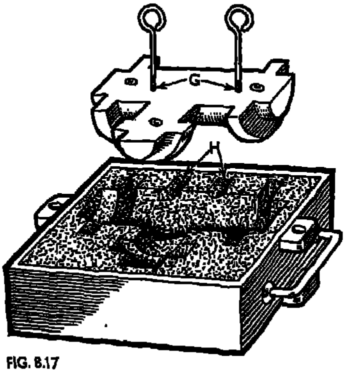


FIG. 8.17

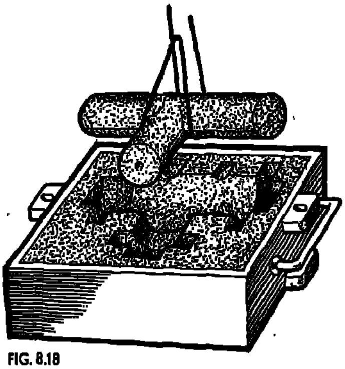


FIG. 8.18

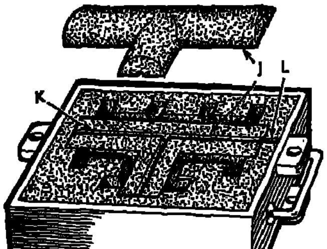


FIG. 8.19

a photograph of a row of moulds made ready for pouring, illustrates the importance of securing free escape for core gases, vent tubes being rammed up in place after closing the moulds so as to prevent any metal splash or overflow (when pouring) from choking the vents.

Cramps are usually preferable to weights for holding half-moulds together during pouring; they permit a clear space for runner- and riser-bushes to be assembled on the top of the mould. Fig. 8.22 (a view of

FIG. 8.20. *Row of moulds ready for pouring. Note the runner and riser bushes, and the vent tubes to prevent metal splashes from sealing the vents.*

pouring) shows this, also a type of push-on cramp, M, that is quickly adjustable to suit varying box-depths and handle positions. In this illustration, burning gases at the bed vents under the mould, and the flame of burning core-gases at N will be noted. Gases at all these points should burn freely during pouring. Fig. 8.23 shows the casting produced from this mould (with the risers, downgates, etc., still attached) and Fig. 8.24 shows the split pattern used to produce the mould.

An example of a three-part pattern is shown in Fig. 8.25; loose-pattern moulders need to gain experience of multi-parted jobs of this type. The procedure for making such moulds, as set out in what follows, is generally applicable to the majority of "more-than-one-joint" jobs. Fig. 8.26 shows the middle part of this pattern at O, with the partly rammed-up mould strickled off as far as the loose-flange collar, P. The flange itself, Q, is then placed over the core-print and tapped down to a hard, level mould-face, partly shown at R. Ramming up is next continued up to the box joint, S, Fig. 8.27, whereupon a tapered stepped-down joint (at T) is strickled out as far as the flange top-face.

As dry parting powder will not easily adhere to a near-vertical sand surface (as at U) positive joint separation must be ensured between these mould faces by applying wetted parting-sand thickly at this point with the finger tips, smoothing out the sand with the heart-end tool or moulder's trowel. After applying the parting medium to the joint, S, the bottom box-part is put on, rammed up and lifted off, as at V in Fig. 8.27.

With many types of patterns, the bottom-part of the mould can be put directly on to the sand bed, as in Fig. 8.28. The loose flange, Q, Fig. 8.29, is then drawn out from the middle section of the mould (Q1), and this part is next turned over and located on the bottom half, as at Q2, Fig. 8.30. The other half-pattern, W (Fig. 8.30), is then put into place and the top box-part rammed-up as usual, then lifted off and placed on the trestle, W1, in Fig. 8.31. The middle section of the pattern, X, is drawn out as shown and the lower drawings in Fig. 8.31 show the completed and opened out mould, also, the body-core, Y, and a finished casting, Z. The advantages of loose box-pins and interchangeable double-lug moulding boxes for this type of loose-pattern bench moulding will be apparent from this description of three-part moulding. Fig. 8.32 shows a pump casing for which four-part-box moulding, on similar lines to the method described for three-part moulding, is necessary.

MOULDING FROM ODDSIDES

A large number of solid (one-piece) patterns which possess no convenient flat face to work from are moulded "loose" and for these an "oddside" of sand or other material (often plaster) is a convenient device

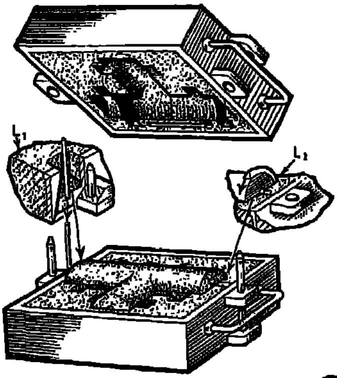


FIG. 8.21

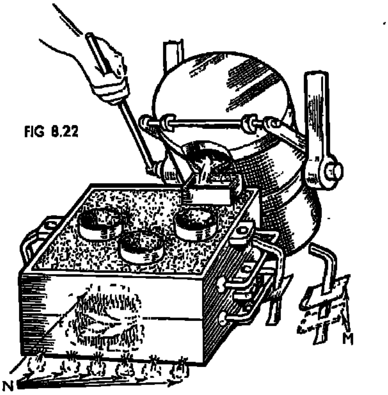


FIG 8.22

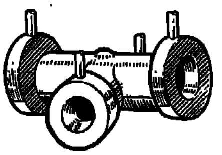


FIG. 8.23

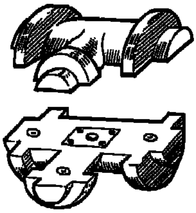


FIG 8.24

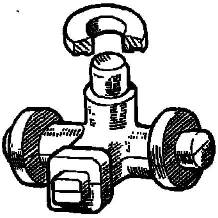


FIG 8.25

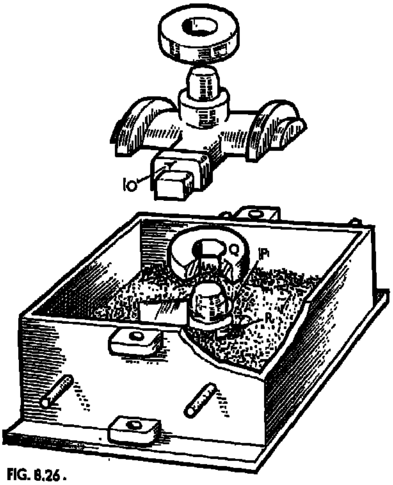


FIG. 8.26.

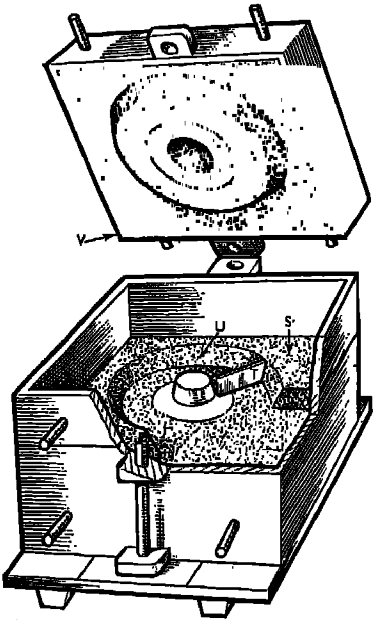


FIG. 8.27

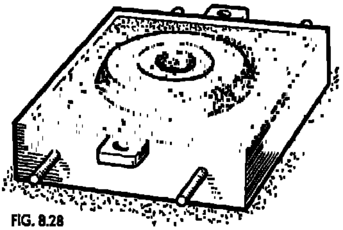


FIG. 8.28

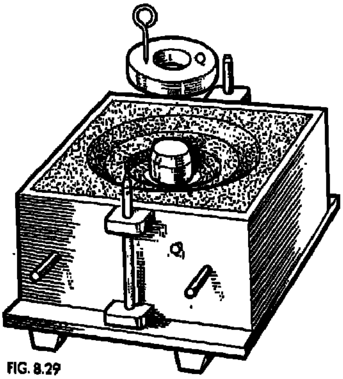


FIG. 8.29

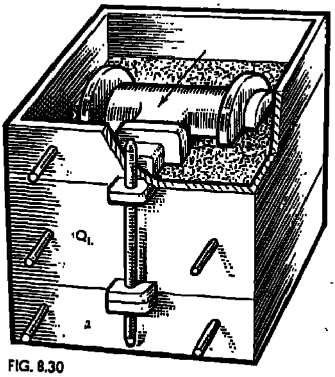
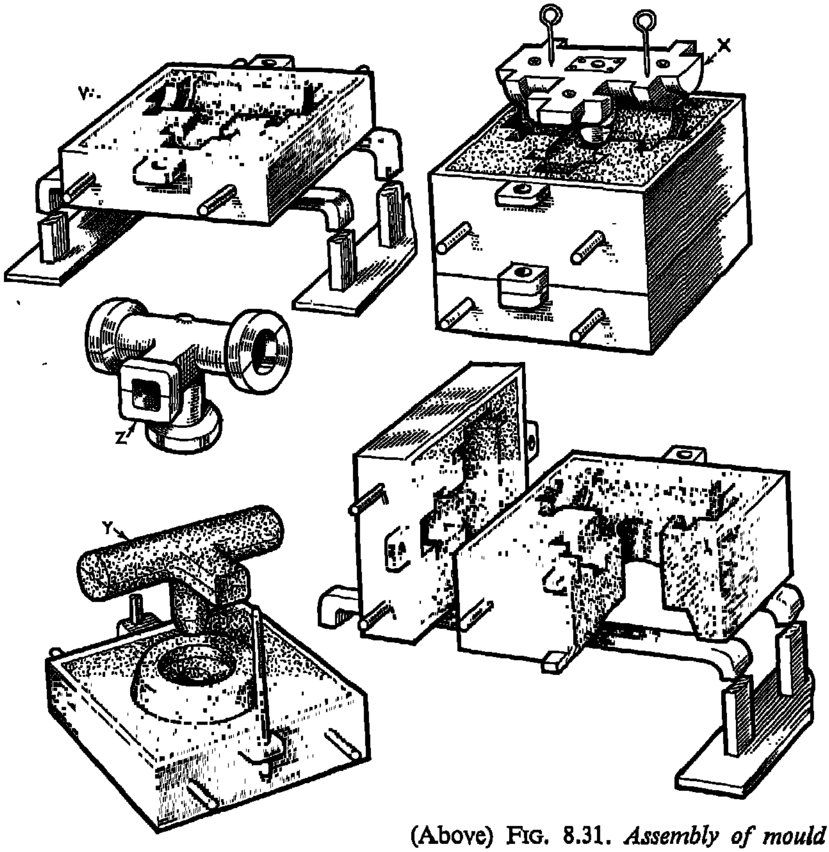
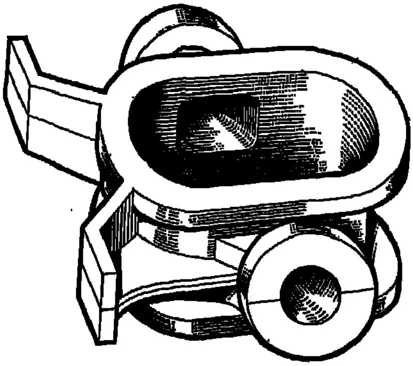


FIG. 8.30

to employ. An oddside is, in effect, a spare half-mould in which a one-piece pattern may be bedded in such a manner and position as to enable a symmetrical moulding-joint-line to be arranged to permit a first "production" half-mould to be rammed up from it. The sketches in Fig. 8.33 show stages in the production and employment of a sand oddside for bench moulding from a solid pattern. This system is in common use for most



(Above) FIG. 8.31. *Assembly of mould and cores produced from three-part pattern.* (Below) FIG. 8.32. *Pump casing requiring four-part box moulding.*



patterns irrespective of size, i.e., from the small casting, shown at A, Fig. 8.33, to the one-piece bed-plate pattern to be illustrated later in the section dealing with heavy-moulding work.

For making such an oddside, a "dummy" top box-part is rammed up as at B, Fig. 8.33, cut out at C to suit the pattern shape and "lifted" as at D, in order to bring the pattern joint-line more or less up to box-joint level. The completed oddside carrying the pattern is shown at

F. Next, a bottom box-part is located and clamped on the oddside and rammed up in the usual way and the assembly is then rolled over. The oddside half is then taken off and discarded (if no further moulds are required from this pattern). The rough sand joint left on the bottom mould is at this stage trimmed to a good shape and parting powder is applied, not forgetting to spread wetted parting-sand on the tapered joint sides at G. The pattern, of course, remains in the bottom part. After placing on another top-part box, ramming is continued, as shown at H. Where there are sections of sand below the box joint-line, these usually have to be supported or carried on "gaggers" rammed-up in place. A gagger iron selected for this purpose, as shown at J, is first dipped in clay-wash and then carefully rammed tightly with a gagger rammer.

With the smaller type of one-piece patterns, it is often advisable to rap a clearance around the pattern before lifting off the top part (for this, the rapping bar, K, is rammed up with the top half-mould, while located in the pattern rapping-hole, K1). Sketches L and M show the completed mould after drawing the "solid" pattern out of the bottom half-mould. The cutting of an inlet gate, a runner-bar and a downgate hole—all to register one with the other so that inlet N comes over the ingate, O—complete this mould.

PRECAUTIONS IN POURING

Research to produce stronger metals for industry is constantly under review by foundry metallurgists, and their work, plus laboratory trials and extended technical control, has developed metal mixtures and compositions that meet, without difficulty, the various specifications set out for high-duty components. Pouring of moulds at defined metal temperatures, running speeds and under controlled methods, now produce castings to a very high-class standard.

The majority of molten metals when exposed to atmosphere oxidize in some degree and produce surface "dross" varying in amount with the type of alloy being melted. Fluxes are available, particularly in non-ferrous foundry practice, to "float" off these undesirable inclusions which would otherwise be conveyed via the running system into the casting cavity when pouring a mould. Likewise, metal turbulence, created by incorrect methods of pouring, or badly designed running systems (also mould or core agitation) can produce a surface crust on castings, removable in many cases only by excessive and expensive machining. Even molten cast iron is rapidly affected adversely by turbulence; this can be observed by pouring metal from one ladle to another once or twice. The agitation caused by gas bubbles can also be demonstrated if the lining of one of the ladles be slightly damp. Exactly the same "scrap-making" conditions prevail when

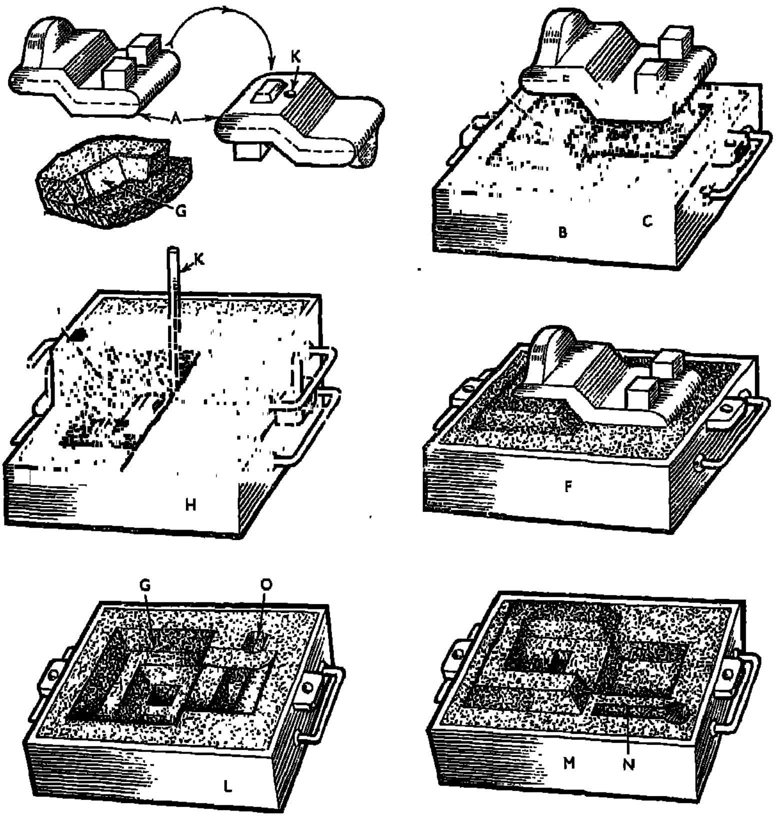
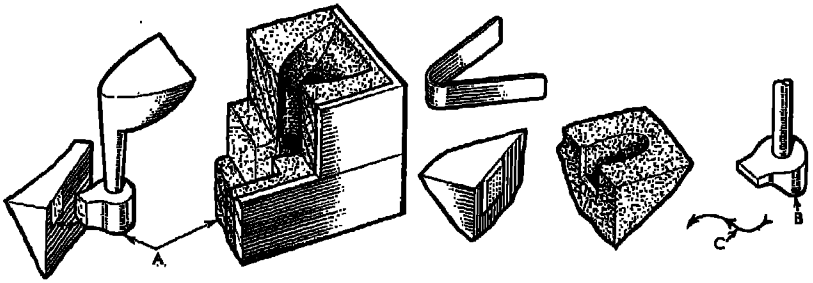


FIG. 8.33. *Oddside moulding from an asymmetrical solid pattern.*

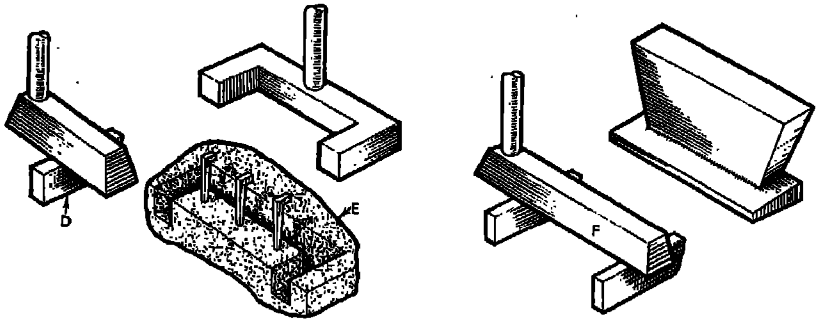
pouring moulds and many different types of running methods (as shown in Fig. 8.34 a to g) have been evolved in the effort to ensure that clean metal flowing into a mould space remains quiescent, with as little disturbance as possible. "Dirty metal," caused by turbulent running, is a primary cause of scrap castings.

RUNNING SYSTEMS

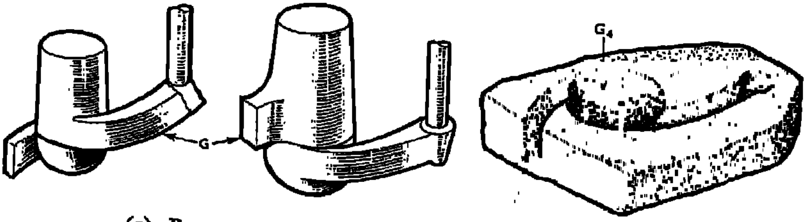
The average loose-pattern moulder, if left to his own devices in designing a running system, will usually adopt the obvious and easiest way of introducing molten metal to his mould, that is, "straight down and in" (as at A in Fig. 8.34a) with, very likely, a vortex-inducing scooped-out runner basin. As a further example, an oversize downgate placed directly over a narrow small inlet gate (B, Fig. 8.34a) will put a "hosepipe" type of jet on the metal entering a mould (as indicated by the arrows, C).



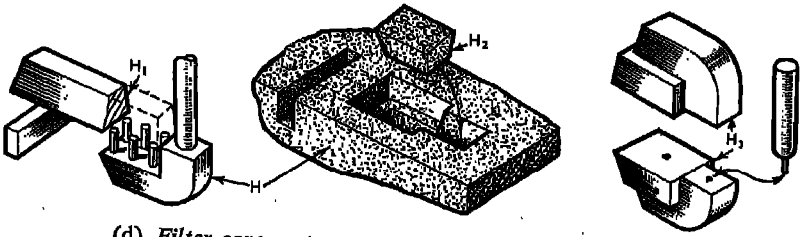
(a) *Vertical downgate with scooped-out runner basin.*



(b) *Runner system in bottom half of mould.*

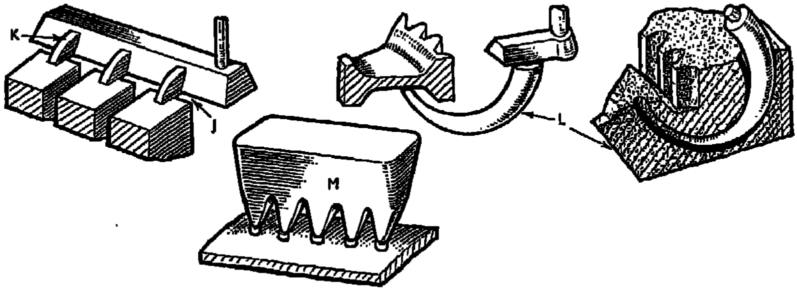


(c) *Runner to spin metal-dross to centre of knob.*

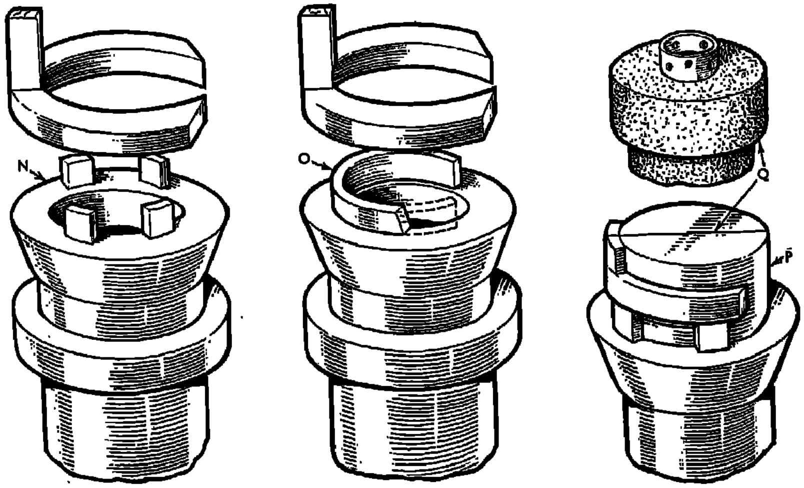


(d) *Filter-core system.*

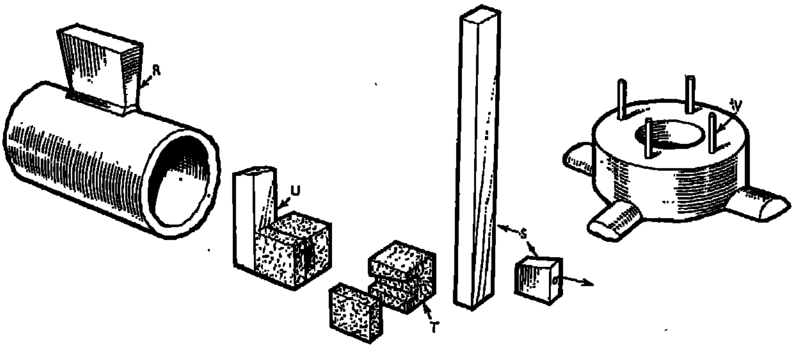
Parts of FIG. 8.34:



(e) *Runner-feeders, and a horn runner.*



(f) *Horseshoe runner-bar for liner castings.*



(g) *The wedge runner and pull-in bottom runners.*

FIG. 8.34. *(Continued)*

FIG. 8.35. *A pouring ladle, incorporating a refractory skimmer-plate and designed for easy operation by one man.*

The alternative adoption of a plain runner-bar and ingate, type D, will prevent metal pressure from the runner bush and downgate from bursting the runner section leading into the mould. The runner system shown at E (Fig. 8.34b) is cut completely in the bottom-half of the mould and as it is liable to burst, due to the metal pressure, moulders' sprigs need to be pressed in as shown for reinforcing the sand at this point; sketch F shows a simple alternative system where no sprigs are needed for reinforcement.

The runners shown at G (Fig. 8.34c) serve to spin metal-dross to the centre of the "knob" in a most effective way (this can be observed by watching an open "knob" during pouring). It is good policy where possible to work the runner-bar, G1, spin base, G2, and the inlet gate, G3, in the bottom-half of a mould; two moulders' pins (as at G4) will make secure the mould section at the curve, if this comes too near the edge.

The filter-core running system, shown at H in Fig. 8.34d, has proved very successful with many thousands of small- and medium-size lathe-chucks and other extensively machined castings, from both machine- and hand-made moulds. It works well even when the man in charge of pouring is inclined to be slipshod in his methods. Sketch H1 shows a complete filter runner taken off a casting; H2 shows the filter core itself, which is inserted into the impression below it, the latter being made by the "standard" pattern-detail H3, which can be rammed up loose with a pattern or fixed along with the other details (runners, etc.) on a patternplate. Any "dirt" from a runner-bush entering such a device will be separated from the metal by the filter core.

The runner/feeder top-bar, J (Fig. 8.34e), when taken close up to the edge and arranged with top inlet-gates, K, will confer solidity on small castings which incorporate heavy sections or isolated bosses. The horn type of runner, L, is popular when casting gear-blanks and the like, and porosity in the rim of such a casting—sometimes visible only after machining and yet identifiable as coinciding with the inlet-gate position—can be eliminated with this system of running. The runner pattern of design, M, is suitable for producing thin-section castings of large area, where a "flood" of hot metal is required. For vertically-poured liner castings, the casting end shown at N (Fig. 8.34f), carries a "horse-shoe" runner-bar with four downgates (often called pencil gates) below it. Sketch O shows a "flash" runner inlet and P shows the coreprint on a liner pattern with runners incorporated. By increasing the coreprint diameter and also that of the spun-loam core, Q, the inflowing metal is directed between the core and mould face; this system prevents any likelihood of scouring action between molten metal and core face.

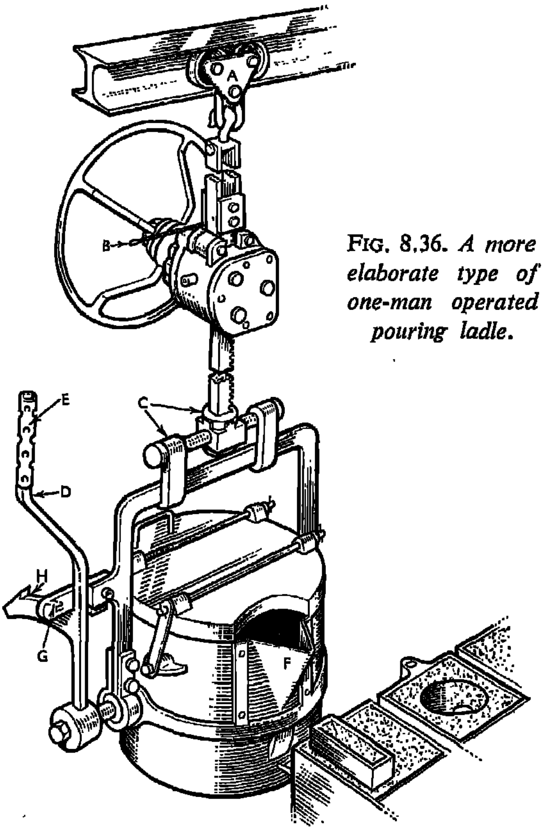


FIG. 8.36. *A more elaborate type of one-man operated pouring ladle.*

Finally, the wedge type runner, type R (Fig. 8.34g) is often used for pipe production and for other castings where no machining is necessary. Bottom runners can be of the "pull-in" ingate type as sketched at S, or filed out of two pieces of dried core (as at T), rammed up *in situ* opposite the downgate U. Pencil runners are shown at V.

Many of the advantages gained from careful planning and placing of runner-bars and ingates can be offset by the choice of unsuitable pouring methods and the wrong type of bushes or basins.

LADLES AND POURING BASINS

The single-operator pouring ladle shown in Fig. 8.35 was developed to provide a head of metal which would bring to the top any scum formed while pouring was in progress and prevent it from entering the moulds. This is effected by the incorporation of a refractory skimmer-plate in the ladle lining which ensures pouring in the manner of a tea-pot, the metal being drawn from the bottom of the ladle. An air cylinder and handy valve control unit when built into the ladle suspension system provides a fine control of hoisting or lowering. The comfortable stance of the operator will be noticed.

Fig. 8.36 (a) shows an improved model of a one-man pouring ladle, attached to a rack-and-pinion hoist. In foundries where headroom is restricted, the hoist can be supplied with gear and chain contained in the gearbox. In this model, the ratchet release lever, B, permits a quick lowering, with one hand on the wheel for braking. The pouring position of the ladle is only fixed in relation to the handwheel, by C. The hand-pouring lever, D, has a drilled extension tube, E, which serves to keep the handle cool during long periods of use.

The type of ladle lip, F, can provide as little as a mere trickle of metal when required. When using the retaining bar, at G, movement is limited, and permits pouring of only the first hundredweight or so of metal from the ladle. A second notch, H, prevents a full ladle from tipping right over if the pouring lever is loosed accidentally. Other parts of the sketch of the ladle are self-explanatory.

Fig. 8.37 shows a number of different types of pouring basins, bushes and boxes. A1 is the scooped-out or pressed-in-the-mould type for which the downgate is usually cut with a runner tube or alternatively rubber sprues can be adapted to form the downgate when employing squeeze-type moulding machines. Type B1 is a round, plain pouring-bush; and C1 a rectangular pouring-box. In D1, the stopper, or plug, over the downgate is lifted out only when the pouring-box is full of metal. Sketch D2 shows a "skimmer-tin" which may be held by two moulders' pins in position over a downgate, thus holding back the flow for a few seconds until the runner-box is full of metal. At E1 is shown the pouring-box/filter-core method; here, the coreprint impression is made by the sleeve, E2 (which is free to move up or down the runner peg or cutting tube), being depressed into the mould top-face to form a seating for a filter core.

F1 shows a pouring-box which utilizes a separator; the insertion of a bar core, F2, serves to skim the metal, which flows under the bar and into the downgate inlet. When worked in conjunction with a runner stopper, the method provides one of the cleanest ways of running castings.

G1 and G2 show two designs of pouring-boxes made in core-sand;

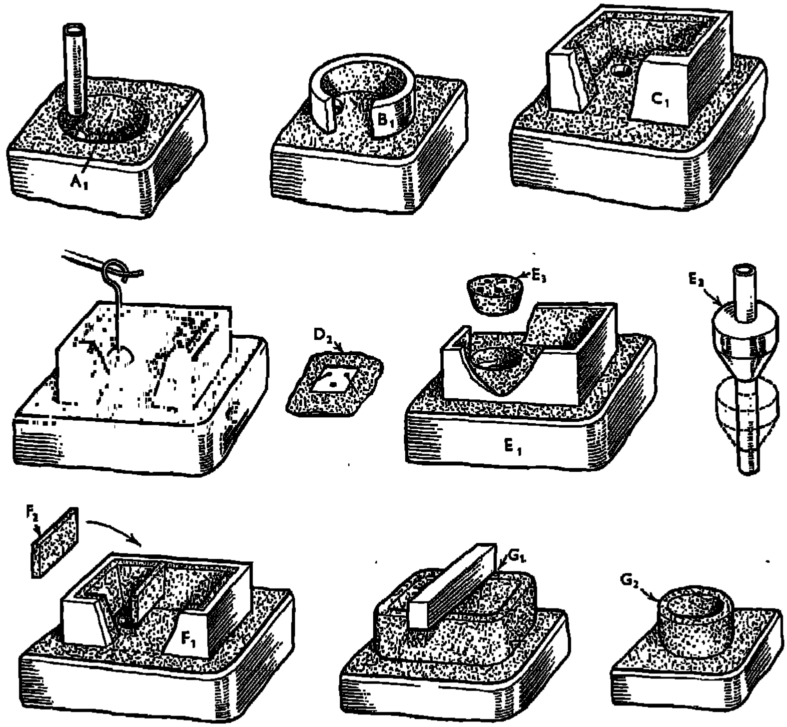


FIG. 8.37. *Various designs of pouring basins.*

these must be of substantial section and of strongly bonded material to contain the molten metal without breaking down until it is solidified. It is necessary to weight down such pouring-boxes as otherwise they are light enough to float away when pouring commences.

FEEDERS AND CHILLS

To ensure solidity in the varying sections and intricate designs of engineering and high-duty castings is sometimes a difficult problem for moulders. Many important components are cast in so-called "hungry" metals, namely metals or alloys which shrink or "draw" extensively after being poured. Both ferrous and non-ferrous metals require feeding in different amounts according to type to offset molten shrinkage and prevent any likelihood of porosity in the finished castings. In differing degrees with different alloys, it is advisable to promote directional solidification, that is, progressive movement of the solid/liquid interface of the cast metal in a mould towards the hottest—usually, the last poured—metal. A whole science has been built up around this problem of providing liquid feed metal to compensate for continuous shrinkage as metals contract before and during solidification.

One device often resorted to to ensure directional solidification is the use of chills: masses of cold material (usually metal) inside or forming part of a mould and which serve to initiate and promote solidification. Then, remote from the chill and at the last part of a casting to solidify, a reservoir of molten metal is provided which can flow into the casting as it shrinks; this is the feeder metal and the space it originally occupies is called a feeder head or "knob."

Because of the high shrinkage of such metals as steel and malleable iron, quite large amounts of feed metal compared with the weight of the casting have to be provided. It follows that with such metals, the yield (ratio of good castings produced to weight of metal poured) is low, and hence, many expedients are resorted to to improve matters. It also follows that the designs of castings for which it is most difficult to arrange directional solidification are those which have substantial variation in section thickness in different parts.

One example of an intricate design requiring careful consideration of feed-metal provision is a diesel block shown in Fig. 8.38. This multi-cylinder casting has a section variation from ¼-in. (at the cast-in water-cooling service pipe) to the 3-in. internal bosses for holding studs which are integral with the substantial liner-flange seatings. Top-pressure feeding cannot well be applied to castings of this type and resort has to be made to localized chilling, a method which requires full exercise of a moulder's skill.

Fig. 8.39 shows a machine-tool gearbox casting, where imaginary details have been put in to illustrate a few typical feeding and chilling methods used to promote soundness in a casting. Any one of the methods shown can be adopted with confidence to isolated bosses or sections which are prone to "draw." A and B show an ordinary top-pressure block

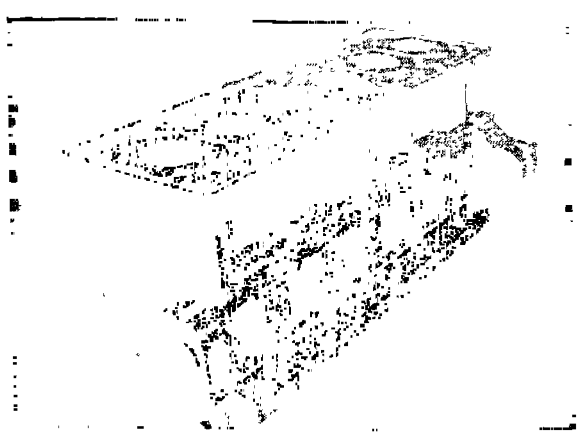
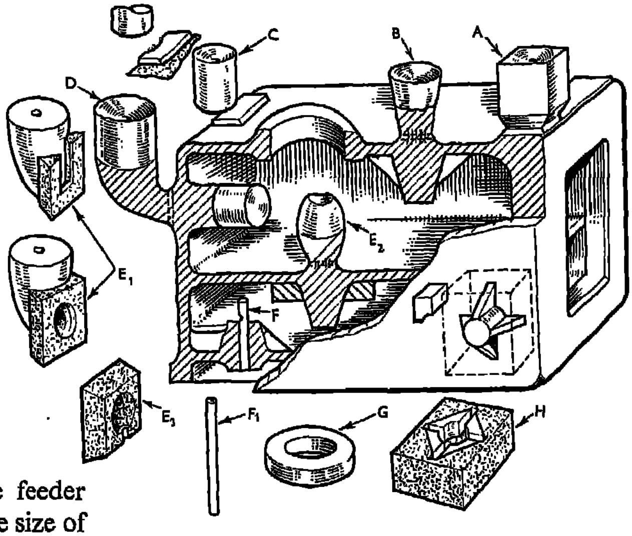


FIG. 8.38. *Diesel-engine block casting —an intricate design of varying thickness.*

FIG. 8.39. *Imaginary gearbox casting, to show various methods of feeding and chilling.*



feeder and cone feeder respectively. The size of these in relation to the casting section (or boss size) is important. Sketch C shows an edge-type feeder (sometimes known as a Connor runner); it is remarkably efficient and leaves little or no chipping piece to be fettled off the casting. At D is shown a side-knob: these types prove excellent feeders and are often preferable to top feeders. The chipping-piece cores E1 are made in a core box and permit the knob-pattern to be worked close to the casting.

Rectangular (or round) chipping-piece shape can easily be filed or stoned in the cores and thus one core box will cover many sizes of feeding necks and knobs. Sketch E2 shows a core-box-made internal feed-knob which is rammed up in the core. In making this, two half-cores (one shown at E3) are stuck together, the chipping-piece shape being filed in to suit. Internal knock-off feeders are, of course, made of a size which permits their removal through openings in the castings.

Alternatively, for chilling or densening metal internally, a cast chill pin, F, can be inserted when the body core is being rammed up. These pins serve to "freeze" any boss to give a close grained, high-density metal. The pin diameter must be less than that of the hole to be drilled in the boss and a saw notch will induce them to break off flush. (Steel or wrought-iron rods should never be cast-in when making iron castings as the difference in the materials may cause a drill to run off-centre when machining.) Cast-iron sticks for use in this manner as chills are easily made by ramming up a dozen or so at a time, using lengths of bright steel of various diameters (F1) as patterns. For providing supplies of small, ¼-in. diameter chill pins, a plum-ended vent-wire may be stabbed down into a hard-rammed mould and the holes filled with "hot" iron from a light hand-ladle.

Sketch G, Fig. 8.39, shows a ring chill which makes quite an efficient heat-exchanger for location at isolated bosses, wheel centre-bosses and the like; H shows a core with chills for external ramming up "on-the-pattern," the chills between the brackets being rammed in place when making the core. Patterns for exterior mould and corebox chills to almost any desired shapes can easily be made in air-hardening core-sand and then dried or CO_2-hardened sand can be employed to make these sand patterns. Filed flat-back and tapered, such chills can be produced from a simple pattern put into any spare space on a patternplate and thus cast along with production jobs as and when required. All external chills should be discarded after being used for not more than six times. Creosote or tar varnish is a safe coating for chills and molten metal will "lie" quietly on all except "burnt chills," that is, those used too many times.

COVER-CORES

The recent development of the cover-core or block-core system of hand-mould production of castings has helped considerably to reduce the pressure on the skilled loose-pattern section of the moulding shop. This method can easily be adapted to existing solid, or unevenly-jointed patterns and, in many cases, by using a "cover-core" as a base or oddside, semi-skilled trainee moulders can produce first-class moulds every time. Block-core bases for "one-off" castings when shaped up by a skilled moulder and used (after drying) as an oddside, will remove many time-consuming operations previously accepted as part of the skilled loose-pattern moulder's routine.

When adopted for intensive pattern-plate and machine-moulding production, the cost of making cover cores is easily recovered in many ways. When applying this one-box moulding system, the saving in expensive moulding boxes and other tackle will be obvious, box-parts of light-section welded steel, or those of quickly detachable (after pouring) tapered-wood construction can be utilized in certain cases.

The few examples chosen for illustrating this section are typical everyday jobs and the ideas incorporated are readily adaptable to dozens of others, needing little by way of explanation. Fig. 8.40 shows a small rocking-lever pattern, A, adapted to form a cover-core, B, both the cover-coreprint and the cover-corebox are moulded by hand and "cast" in a hard-setting artificial-stone type of pattern material, the existing pattern being fixed into the print, C. A stepped-jointed wheel pattern, D, can be mounted in like manner when the small numbers required rule out the use of a cast pattern-plate or other expensive mounting method. The adoption of a flat-back cover-core method of production permits these unevenly

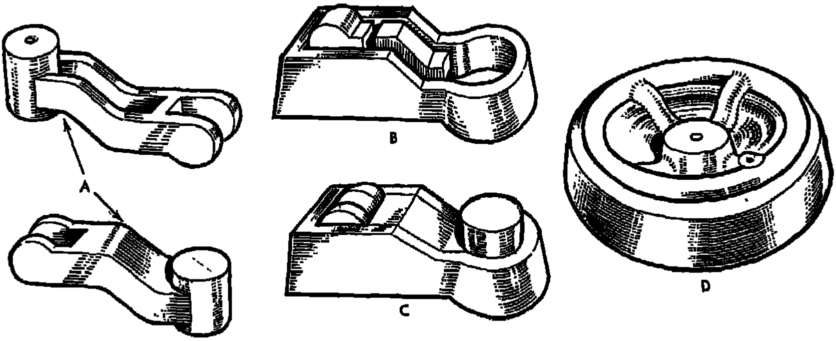


FIG. 8.40. *Rocking-lever pattern adapted for cover-core moulding.*

jointed jobs to be worked in any spare corner or other free space on an existing pattern-plate in current use.

Fig. 8.41 shows a siphon-box pattern conversion from the all-mould method at D, to the one-box cover-core method at J. The necessity of ensuring release of core gases and the machining requirements indicated the desirability of moulding the job face downwards. Previously, the core was placed in line with the box pins, F, on chaplets, H, to ensure that the coreprints (cut through in the top) came to proper register when closing the moulds. The risks of such a course will be apparent.

With the one-box cover-core mould shown at J, chaplets are unnecessary and thus possible scrap castings from improperly absorbed chaplets are eliminated. Fig. 8.42 shows the simplicity of production by this method; a dab of core-paste on the print ends, K, secures them in the cover-core shown at L; the edge-runner, L1, at the top leaves little to be fettled off.

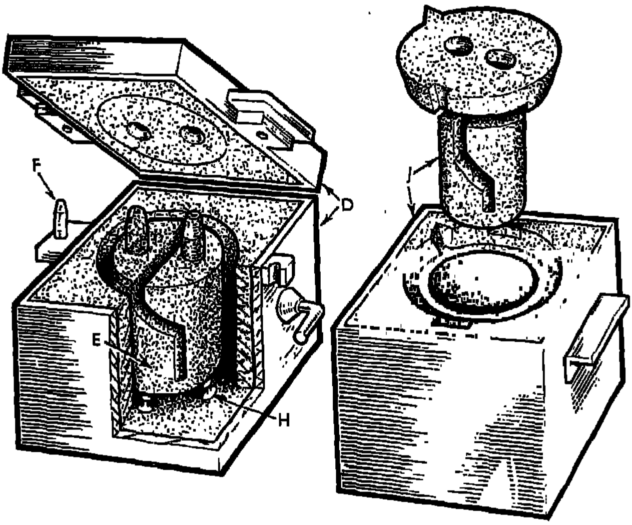


FIG. 8.41. *Mould for siphon-box casting converted to production from cores.*

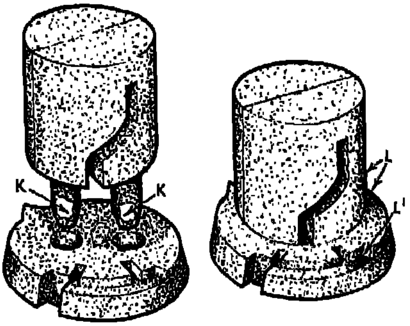


FIG. 8.42. *Simplified production of the core for the siphon-box casting.*

The open prints in the "all-mould" (Fig. 8.43, M) have to be sealed against metal entry and yet leave an open vent for the core gas, as at N; a cut-in channel under the weight, P, is also necessary. The right-hand sketch shows the one-box cover-core held down with two "bobbins," Q, placed across the edges of the cover-core print and the mould. In this case, the type of mould weight, R, permits easy pouring.

Various sizes of "standard" cover-core prints and cover-core core boxes to match them can be made to suit a wide range of split patterns. Fig. 8.44 shows two deep-draw straight-sided patterns outside the scope of a particular foundry's small moulding machines if they were worked on end. Fig. 8.45 shows a standard cover-core print and cover-core corebox, suitable for forming these. The pre-determined pattern position is repeated each time a mould is assembled and correct register is assured by the dowel pins and holes, V1; loosening the wingnut, V2, can be made to release the rammed-up pattern, which is rapped and drawn out separately in the usual way.

Fig. 8.46 shows further advantages of a deep cover-core and the shallow cover-core coreprint idea. For the all-mould method of producing this design of casting, shown at W, provision of taper on the coreprint, W1, is necessary for blind closing. The middle and right-hand sketches show the shallow coreprint and deep cover-core set-up, the joint line, W1, being

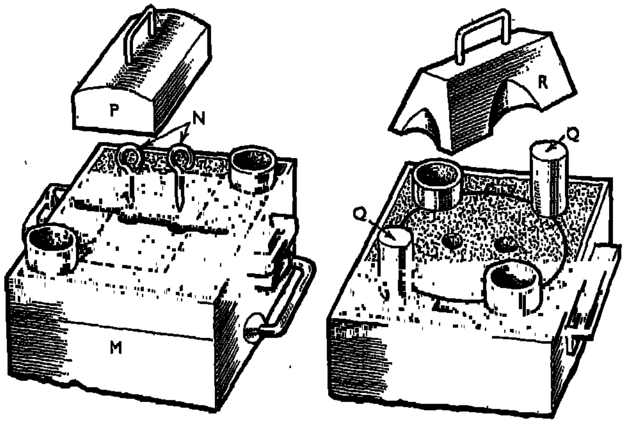
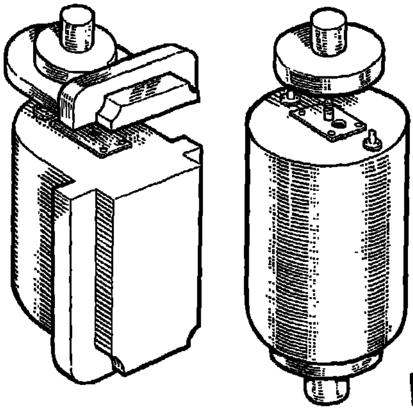
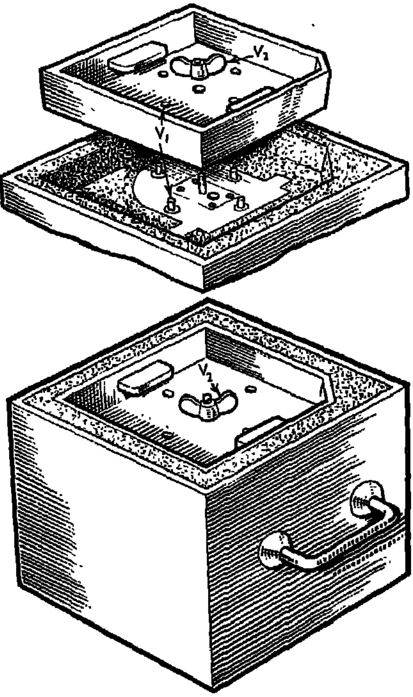


FIG. 8.43. *Closing and weighting the mould shown in Fig. 8.41, and* (right) *method of closing and weighting the core assembly.*

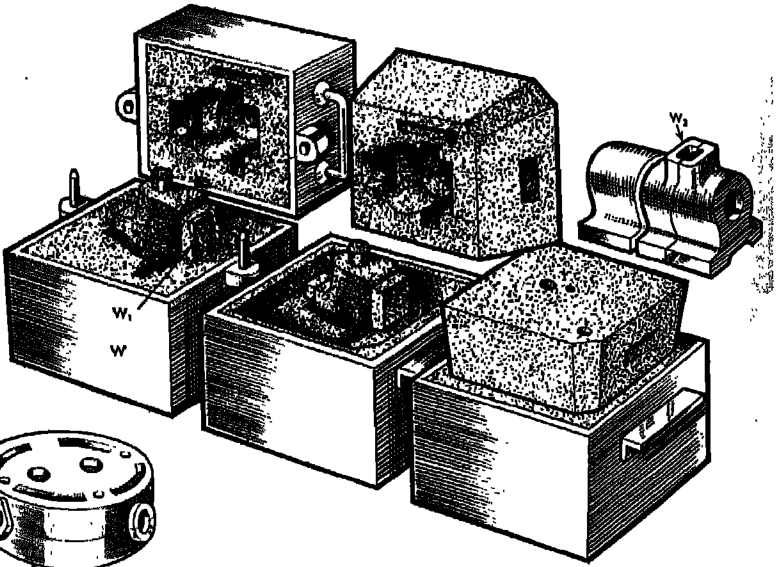


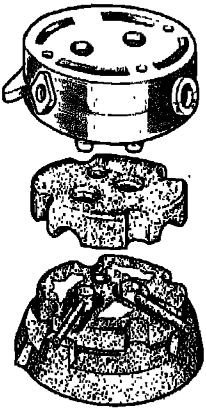
FIGS. 8.44 (left) *and* 8.45 (below). *The cover-core method applied to long, straight-sided cylindrical castings.*



indicated at W2 on the casting produced in this way. Similarly, Fig. 8.47 shows the cover-core arrangement applied to an intricately cored water-cooled cylinder head, where open vents are assured by the method. It is contrary to normal practice to cast the machined face and valve seats that way up, but the choice of method has shown no visible ill effect among many thousands of castings of various sizes in the range produced in this category at the particular foundry in mind. Metal turbulence is absent with the fixed-in core-assembly and with the (dried) running system arranged in the cover core.

Figs. 8.48 and 8.49 illustrate a well-established cover-core system applied to the production of diesel-engine pistons; Fig. 8.48 shows a group of true cores mounted on cover cores and Fig. 8.49 shows a sectioned mould; uniformity of metal thickness of the casting to be produced can be checked from the bottom joint-line at X. Fig. 8.50 is yet another example of a moulder-made oddside-type of cover core for a solid pattern. The oddside is dried and serves as the base for the mould—instead of using a normal temporary sand oddside—the pattern being put back on to the oddside after drying and rammed up by the now familiar "one-box" technique. By this method, there is a considerable saving of moulding





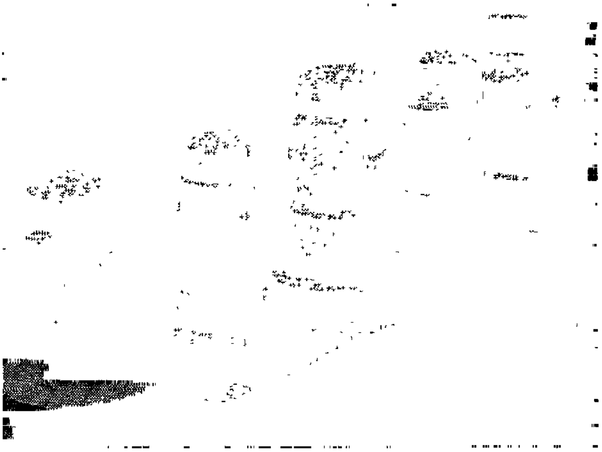
(Above) FIG. 8.46. *A further illustration of the use of cover-cores as alternatives to mould parts.* (Left) FIG. 8.47. *The cover-core method applied to an intricate cylinder-head casting.*

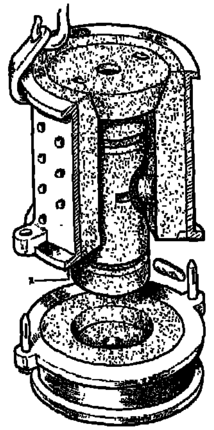
time and joint cutting, gagger lifting and mould-closing hazards are eliminated.

This cover-core oddside moulding can be introduced with distinct advantage into the semi-skilled trainee section of a foundry. The system is only restricted in size by the handling and stoving facilities available and, in the writer's experience, lathe chucks up to 4 ft. diameter are in regular production from green (undried) moulds made in conjunction with one- or two-piece cover-cores.

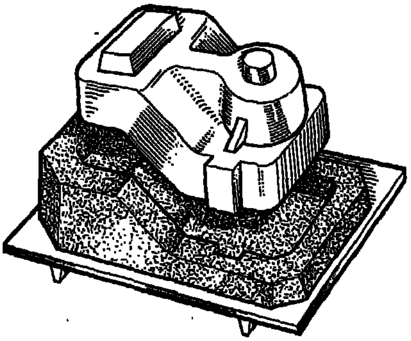
STRIPPING PLATES AND BOARDS

Many patterns are worked "loose" in the skilled-moulder section of foundries which are considered outside the scope of the smaller types of moulding machines or the capacity of semi-skilled moulders. Above-normal pattern depth, inordinate length, intricate or parallel-sided designs, small-quantity orders at long intervals, these and other descriptions which apply to a number of "awkward" jobs, quite often rule out the institution





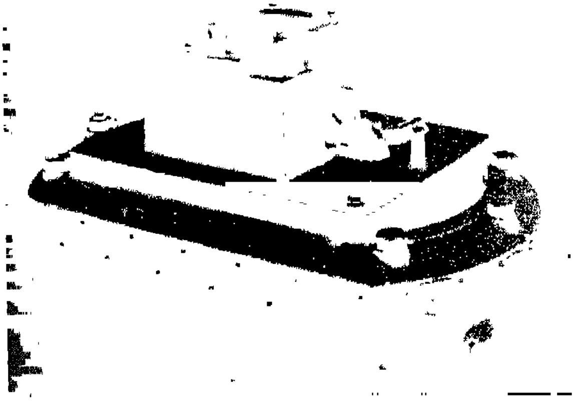
(Upper left) FIG. 8.48. *A group of true cores mounted on cover-cores.* (Upper right) FIG. 8.49. *Core-mould assembly for diesel-engine piston.* (Lower) FIG. 8.50. *Oddside cover-core for solid pattern.*



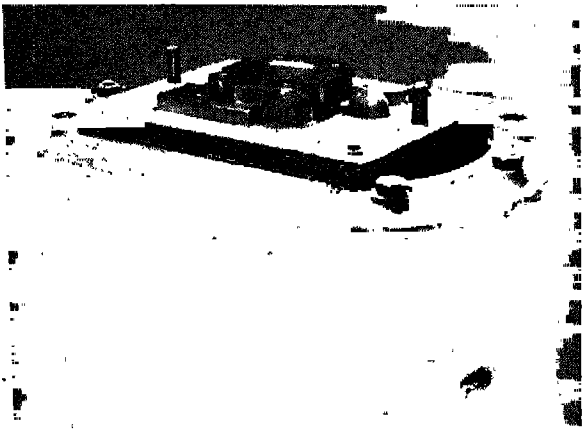
of expensive pattern alterations or the provision of new production equipment.

There is no doubt that for some of these types of castings, the main uncertainties associated with the difficult-to-draw and double-ended lifting of hand-rammed moulds made by semi-skilled operators can be completely overcome by employing what is known as the stripping-plate method. Examples of precision-made, level-jointed stripping plates, as shown in Figs. 8.51 and 8.52, amply justify first cost by their permanency and long, trouble-free service for the rapid production of first-class moulds. The same remarks apply to the two moulder-made strippers shown in Fig. 8.53. The process for making this latter pair of step-jointed pattern units, however, requires a moulding skill of no mean order; equipment to tool-room standard is also necessary.

In complexity between these expensive mould-making sets and the patternmaker-made wooden-board "stripper," there are dozens of split patterns worked loose in the moulder section, which can be adapted to the use of stripping plates in one simple form or another for the production of perfect moulds even from operators who are only semi-skilled. For

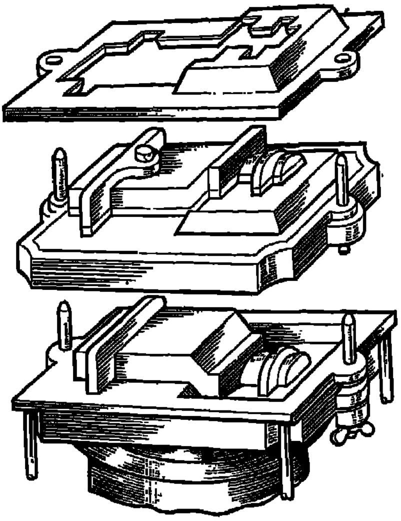


FIGS. 8.51 (right) *and* 8.52 (below). *The stripping-plate method used for precision moulding.*

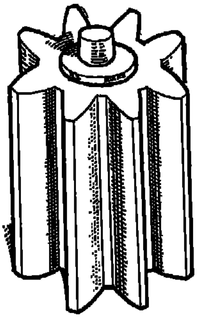


jobs where one-casting-per-day is needed, or say, two dozen are required only occasionally, a saving in production costs will usually justify the expense of making a pair of new moulding boxes and the (detachable) modifications to a pattern necessary for the stripping-plate method of production. The two examples shown illustrate the inexpensive nature of the method, which is applicable to most split patterns.

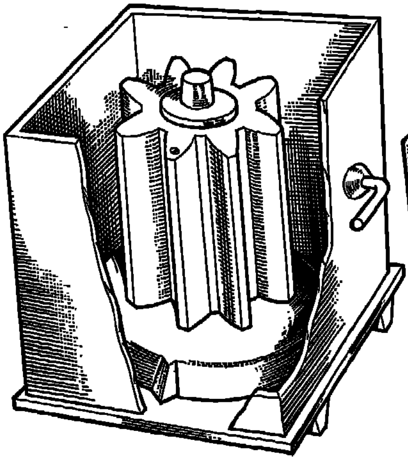
Fig. 8.54 shows a gear wheel for a pump, 10 in. in diameter with eight parallel teeth, each 14 in. deep. This is a pattern outside the scope of any small-draw moulding machine and might be regarded as being impossible to mould on a repetition basis when worked "loose" by conventional methods. Yet, by extending the teeth by the amount of the depth of a stripping cover-core coreprint, as shown in Fig. 8.55, the actual gear pattern can quite conveniently be drawn through the wooden stripper plate, as in Fig. 8.56. Even and hard-rammed moulding courses ensure the production of castings off this pattern which mesh easily without any attention from fitters. The hard-rammed mould and deep-draw, however,

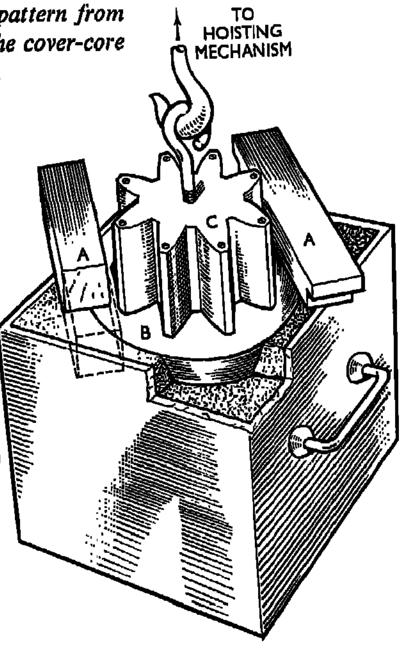


require a power-assisted pattern withdrawal and for this purpose the rack-and-hand-wheel pouring-ladle hoist proves a quite adequate adaptation. Two heavy weights at A serve to hold down the stripper print, B. The extra section of the gearwheel pattern, shown at C (Fig. 8.56) and the stripper core-print, plus a corebox to produce the latter were the only three items necessary to convert the pattern to a one-box-part job. As a result of adopting this method,



(Above) FIG. 8.53. *Frame type of stripping plate and method of use.* (Left) FIG. 8.54. *Gearwheel pattern, 14 in. deep, 10 in. diameter.* (Below, left) FIG. 8.55. *Cover-core extension to the gearwheel pattern to facilitate stripper-plate production.* (Below, right) FIG. 8.56. *Stripping the pattern from the mould through the cover-core pattern.*





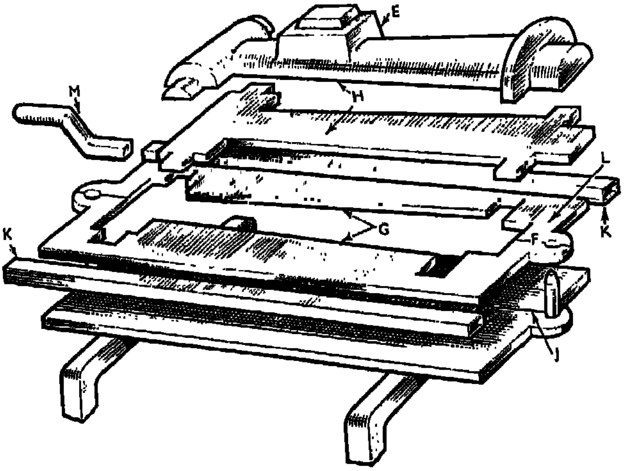
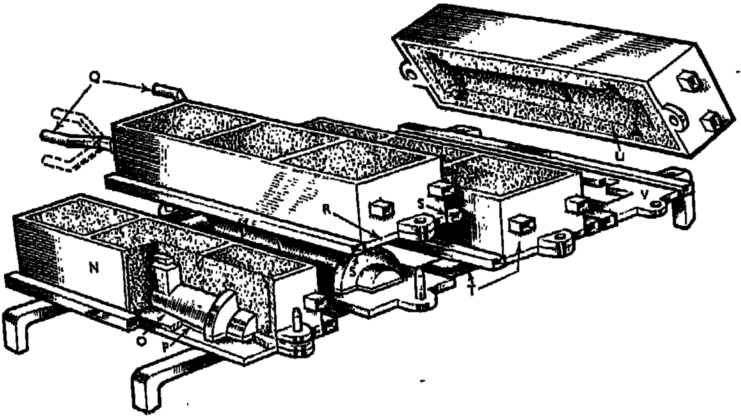


FIG. 8.57. *Stripper-frame applied to a complicated pattern.* (Below) FIG. 8.58. *Use of the pattern equipment shown in Fig. 8.57 for repetition production of moulds.*



one ½-cwt. casting could be produced as a result of half an hour's work.

Many similar deep-draw straight-sided patterns have been adapted in similar fashion, such as mine-sinker drums and other cylindrical designs where a horizontal mould joint was not acceptable.

Fig. 8.57 illustrates one half of a split pattern, worked loose in conjunction with a stripping plate. The simple pattern alteration and ramming only by semi-skilled operator consistently produced this 1½-cwt. casting after only 1½ hours' work. For this, the pattern section E was dowelled separately and attached for a bottom-half mould and detached for a top-half mould, in turn. In making the stripping plate, a mild-steel plate ½ in. thick was marked out on the centre-line, F, and the half-pattern was placed on this line to register; the pattern outline was marked out and the plate cut out by the oxyacetylene cutter just inside this outline, G. The cut-out piece, H, was then fixed on to the underside of the pattern face and the unit fastened to the baseplate, J. Two hollow square-section tubes, K, welded on to the sides of the stripping plate, L, conferred stiffness on the thin plate and also provided sockets for the cranked loose-box and plate-lifting handles, one being shown at M. The complete assembly for this job is sketched in Fig. 8.58, the half-mould, N, being cut away to show details. The stripping plate, O, is an easy fit around the split pattern distance-piece, P. The cranked handles, Q, confer a safe lifting stance for such narrow boxes and can be used also in different positions, upwards or downwards, for deep or shallow boxes.

Rammed-up moulds are lifted off the pattern together with the stripping plate, R, the cranked handles being placed for this purpose into the stiffener-tube sockets, at S; the mould and stripping plate are then placed face downwards on the trestle, as at T. The handles are next changed into the moulding-box sockets and the mould is lifted off the plate, U, leaving the stripper, V, behind; the latter is replaced on the patternplate and the cycle is repeated. Four half-moulds from this same job are shown in turn on the trestle, but actually the daily requirement from this one moulding station would be six different patterns worked in the manner set out. The confidence with which semi-skilled operators can produce perfect moulds quickly justifies the pattern alterations.

HEAVY-BOX MOULDING

Metallurgical development of various types of cast irons has led over the years to the introduction of stronger metals of known qualities of hardness, resistance to torsion, bending, etc. This now permits the adoption of lighter sections of metal than used to be the rule for sizeable castings; previously ignorance of the actual strength of a casting led to the use of heavier than necessary sections in designing, with the objective of providing adequate safety margin.

Nowadays, an all-round reduction in weight of large castings has been possible as a result of designing to embody only sufficient strength where necessary. However, this has by no means simplified the moulder's task in producing such castings; added complication results also from a tendency to replace assemblies of simple castings by one-piece streamlined components. The extra ribbing and bracketing of thin-walled castings leads to difficulty in moulding, yet because of the higher stress concentrations everywhere, there is greater need than ever for the casting to be perfectly sound.

This is the type of work where the versatile moulder, with a background of experience built up over the years, is really indispensable; unfortunately, all too few are reaching this maturity nowadays to replace

FIG. 8.59. *Diesel-engine block casting.*

the natural wastage. With big jobs, it was seldom necessary to keep records of procedure, still less to plan details before commencement; now, however, both provisions are increasingly being adopted, and cannot be too strongly recommended.

Each large casting has to be treated as an individual job. It invariably embodies special features, and there is always the need to reconcile unalterable laws of expansion and contraction consequent on unequal heating and cooling. Similarly, with the more synthetic nature of moulding and coremaking materials, there is often less latitude possible in their handling and working. Some mould bonding materials and corebinders, for instance, generate large amounts of gas and fumes when a mould is poured and these necessitate the adoption of superlative venting arrangements; higher pouring temperatures produce more gas and so the moulder's difficulties seem cumulative.

Nevertheless, basic moulding procedure for large castings is similar to that for smaller jobs; hand ramming at critical spots is essential and reinforcement on a lavish scale is necessary for both moulds and cores, while at the same time easy mould collapse after casting must be carefully arranged, especially with box-like structures, such as that of the multi-cylinder diesel-engine case, shown in Fig. 8.59. The making of the first mould for a casting of the type shown in this illustration is often carried

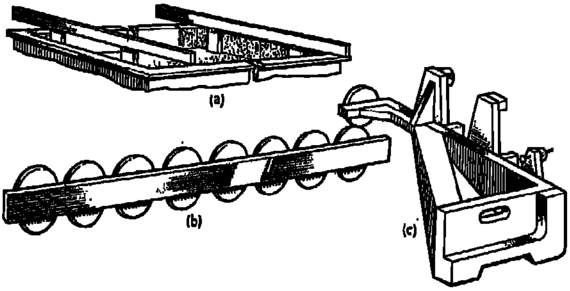


FIG. 8.60. (a) *Sighting rails for checking the accuracy of a mould bed;* (b) *and* (c) *jigs for establishing the accuracy of core and mould assembly.*

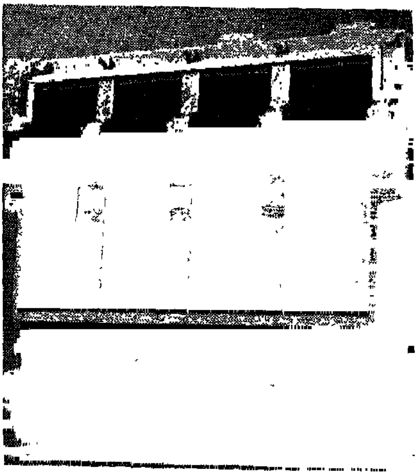


FIG. 8.61. *Pattern for the crankcase of a large engine, needing heavy box moulding.*

out with the patternmaker in attendance and he often marks out the bed and supervises important stages in mould assembly before casting. Checking for accuracy at every phase is important; when, for example, it is realized that the mere picking up or putting down by crane of a large pattern or mould part can cause distortion, the value of such devices as the sighting rails shown in Fig. 8.60 (a) for checking the bed are apparent. Similarly, if a pattern is to be in fairly regular production, the wood-framed checking jigs shown at (b) and (c) are invaluable aids to accuracy of part location. Any bosses out of position in this casting would create difficulties when marking out and probably cause its rejection; the machining allowances on the eight cylinder-bores, for example, would permit but little tolerance for out-of-line errors or incorrect positioning of mould parts.

CRANKCASE PATTERN

For instructional purposes, the pattern shown in Fig. 8.61 has been chosen to permit easy description and cover as many phases as is possible. It requires an oddside as a base, to accommodate coreprints and

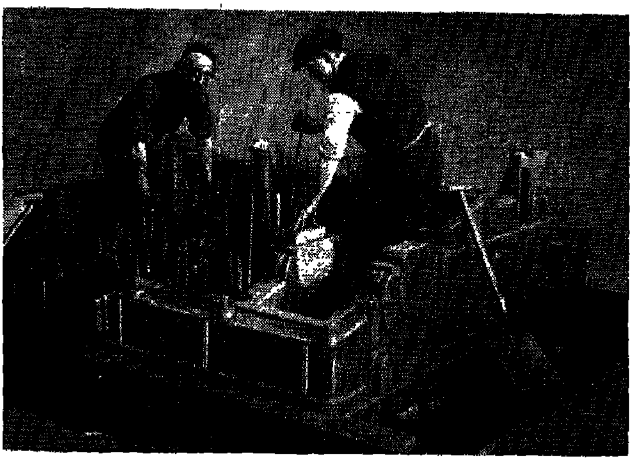


FIG. 8.62. *Crankcase pattern bedded down.*

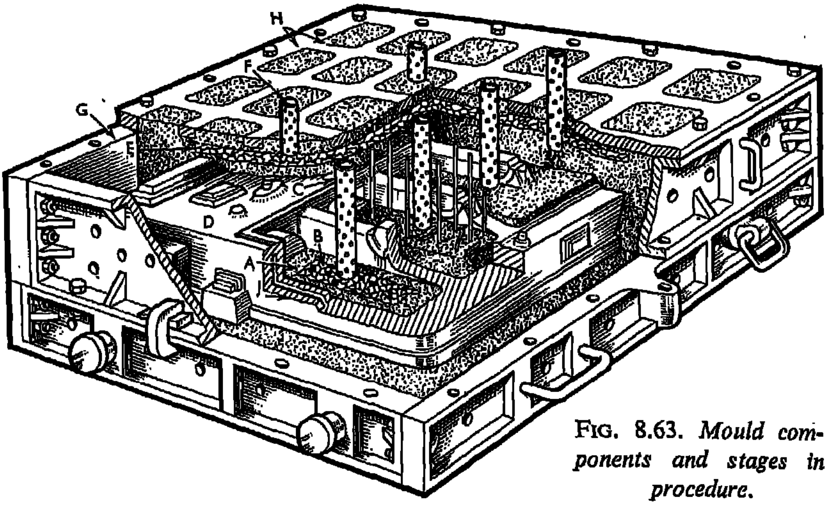


FIG. 8.63. *Mould components and stages in procedure.*

other projecting parts at the rear. As far as construction can make it, the pattern is of rigid framing, but it is not entirely free from distortion when lifted by the "straps" at the corners, seen in Fig. 8.62. When the pattern is placed on the oddside a check for level is made with sighting rails, placed conveniently on important flat faces at each end of the pattern. The patternmaker will usually fix four pieces at one level to facilitate a sighting check; these faces are reproduced in the mould and used again in the same manner when the mould is re-sited after drying; they are "stopped off" when no longer needed.

Methods of moulding external projections will be noted—that is, the half-cored fixed-on type, the dove-tailed small faces and the loose dowel-pegged items, respectively. The cut-away sketch at Fig. 8.63 shows the procedure as continued by the two moulders seen in Fig. 8.62. Three of the four-throw sumps are shown in various stages of ramming up. After two courses of sand are rammed level and to approximately 4 in. deep at A, a 2-in. layer of small coke, or riddled clinker, free from fines, is flat-rammed down on to the sand face, B. Each of four sump-venting pipes (one shown at C) is inserted a short distance into the coke bed and the course ramming is continued. The next sump shows the reinforcing rods, tapped down to within a half inch or so of the pattern face; bent pieces for tying are also placed in progressively during the ramming, up to a few inches above the pattern top face, D. A second layer of cinders (or coke) is then flat-rammed down to a level face, as shown at E, when short vent-tubes, F, are placed on to the coke layer and ramming is continued to a level just above the box-joint.

Next, a separate drag box-part, H (of robust section), is bedded down hard-on to the slightly raised sand face, and then at spacings of a foot or so bolts are inserted to hold it securely in place. Hard ramming is continued up to face level. Then, after splashing the sand face all over with a water brush, the vent-tubes are taken out and the holes left are filled in with small coke, rammed tight. At this stage, the rammed-up mould and oddside are securely held together with bolts—and cramps if necessary—and the job is rolled over. The oddside is then taken off and knocked out, a check being made for level as usual.

As the pattern has been stiffened at the back by sizeable coreprints, there is only a small area of mould joint to be made here. Runner bars, leading to the inlet gates and downgates leading to the risers and feeder-head patterns are put into position and the top box-part is put on and rammed up as usual. Grating gaggers and other reinforcing details are worked in as ramming up proceeds.

This particular pattern has a tall hump-section made separately from the main pattern. To avoid the need for ramming many cubic feet of sand, which would be needed if a full-size box were employed to accommodate the hump, a quite shallow top box-part is employed and this has a section of its bars taken out. Mounted on this, a smaller box-part of suitable size is used to cover the hump, as shown in Fig. 8.64. The all-round advantages secured by making the hump separate, right from patternmaking to the final closing of the mould, will be obvious, and this idea can be adapted in many ways to pit- and large box-moulded castings. Likewise, the saving in moulding time and coring out at the back of a casting is very considerable and can be visualized by the section

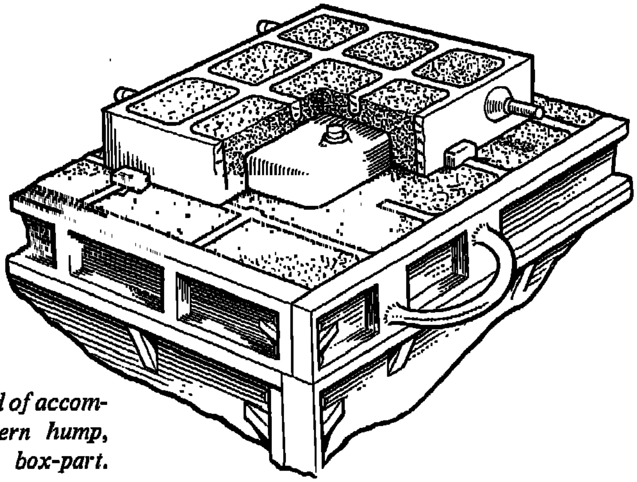


FIG. 8.64. *Method of accommodating a pattern hump, using a small box-part.*

FIG 8.65. *Crank-case mould after withdrawal of pattern.*

shown at J, in Fig. 8.63. The casting section generally is about $\frac{5}{8}$ in. thick, except, of course at the liner seats, brackets, etc. Other details shown in Fig. 8.63 will be referred to later as the description proceeds.

Fig. 8.65 shows the mould after the pattern has been withdrawn, the cut-out vent sections of the mould are taken down to the coke layer or led through side holes in the moulding box. Such side vents from individual core or mould sections can be closely observed, and their efficacy confirmed, during the pouring of a casting. Any coreprint exit in the bottom face can be taken down to the common cinder layer at the bottom of the mould. Fig. 8.66 shows a few traditional ways of ensuring a free outlet from a vent. The almost completely cored-up mould is shown in Fig. 8.67; practically every square inch of the area visible and much more out of sight is quickly covered with metal during pouring. As the metal rises from the bottom face up the side walls, large volumes of gas are generated at pressure and this has to be directed upwards and outwards through the sand faces. If this gas cannot find easy exit, it will blow back

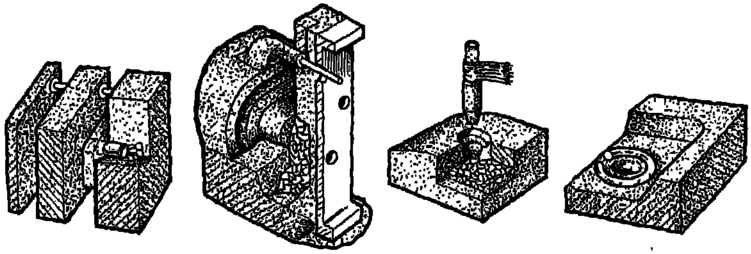


FIG. 8.66. *Four traditional methods of ensuring an uninterrupted outlet from mould and core vents.*

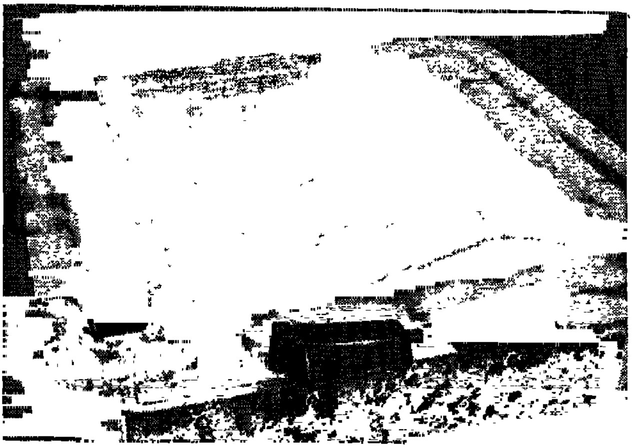


FIG. 8.67. *Crankcase mould with core placing almost complete.*

into the metal or even disrupt the mould, where the sand is not "open" enough to release it.

The coreprints, seen on the higher parts in Fig. 8.67, are tube-vented to provide free outlet for gas (detailed in Fig. 8.66) and to prevent the internal pressure from driving molten metal during casting to penetrate the joints and "cap" over the prints. A roll of soft clay of the type used to seal a bottom vent of a heavy core will be noted in the right-hand sketch. It is a significant fact that any two dried mould or core faces seldom make contact all over a mating face, and metal pressure can cause a "flash," which, even of paper thickness, is yet sufficient to seal a vent exit and cause untold harm to the casting. "Floating" or "semi-floating" cores, equipped only with side vents, can be kept "open" by means of a short tube pushed into a handy cut-out section—formed in this case in the sump body. Such a dug-out section is, of course, made up to correct shape later, the metal tube will serve · also to "freeze" (cause

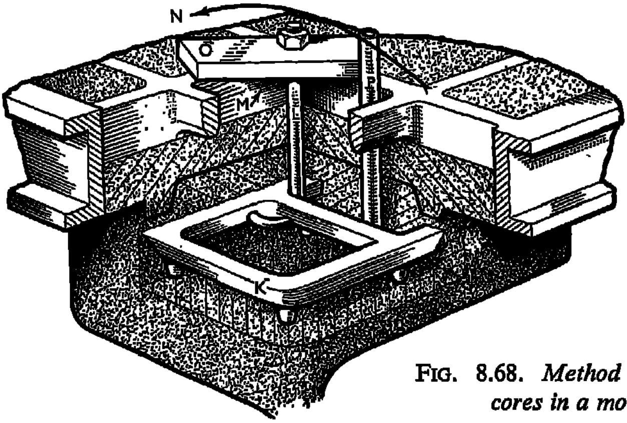


FIG. 8.68. *Method of securing bulky cores in a mould top-part.*

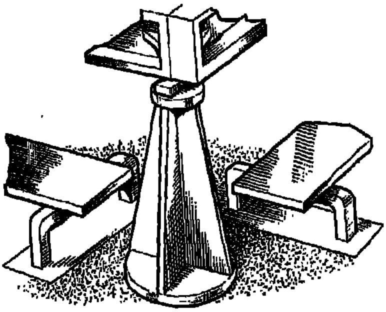


FIG. 8.69. *Mould supports to permit finishing-off underside and face of top part.*

to solidify) any metal which may strike down between the cores. There is no main coreprint to these "floaters"—the left-hand sketch of Fig. 8.66 indicates the way in which they are employed.

In many cases, with large patterns, it is necessary to make provision in the top-part moulds for securely fixing heavy and bulky cores, which are to be held in suspension when the top is rolled over for closing; Fig. 8.68 shows a cut-away, face-down section of the top part for the mould shown in Fig. 8.67, where this is in fact done. The cores, of course, are lowered into position with the mould the other way up from that shown in the sketch. To make a safe working position for operations underneath, a mould is placed in a level position on stands, Fig. 8.69, or across an open moulding pit. Substantial core-grates (or grids) shown in Fig. 8.68 at K, are essential for bulky cores; three or four sand sections are cut out down as far as the core-grid when making the core (as also similarly in sections of the mould core-prints in about the same position); these serve for inserting hooks, etc., when anchoring and carrying the cores. Wherever possible, hook-bolts (as at L) should always be worked into a corner position in the box parts, for example, as at M, to prevent any slight sideways movement when rolling the top mould over in the direction indicated by the arrow at N. The fish-plates, O, should be so substantial as not to bend when the nuts are tightened down, or with the load suspended after rolling the job over and replacing it on the stands.

TRIAL CLOSINGS

A distortion-free, dead-level crane lifting action is most important for the successful making of cored-up top moulds of large area. When using the crane, each chain-leg should be given an equal load by adjusting tension-screws provided for that purpose. Before first lowering of a top part on to the bottom part of a cored-up mould, soft rags are packed lightly into the spaces between the cores and mould, etc., and rolls of soft clay ("sausages") are spaced out on important faces. This soft clay will compress as the top-part seats during the "try-on," and serves to indicate the section thickness left for metal at the various points. (Reference to Fig. 8.70 shows the method applied to the separate hump-section of the top mould-part.) A light dusting with parting powder on the rolls of clay —and chaplet "blobs"—will prevent these from sticking on the top mould when this is lifted off after the try-on. It is quite usual to cramp, bolt, or weight down the closed mould at the try-on stage in the manner finally intended. Thus, any high spots which might "crush" at the final closing are then revealed at the try-on stage and can be rectified.

After taking the top-part of the mould off again and putting it back on the stands, the clay rolls and blobs are checked for correctness of section thickness. Any areas giving too-thin a section in the finished casting are ground or filed away in the top mould until the casting section is correct, as revealed by check closing a second or third time as necessary, employing fresh clay rolls. At this stage, also, chaplet sizes required are checked separately against the side of the squeezed clay blobs, as at R, Fig. 8.70. A small "pile" of white chalk, scraped on to each chaplet with a pocket-knife will indicate a hard-contact or otherwise when making a trial closing. The white powder will also indicate the exact position of a chaplet when these come into contact with the top mould at the second try-on, which is carried out in precisely the same way as the first. If the second try-on is approved as being satisfactory—following a meticulous checkover for stray clay blobs and bits of broken rolls, crushes, etc.—the rolls and blobs are then removed and the whole area is brushed or blown clean. The spacing rags S are then carefully pulled out to bring with them any loose sand or clay, and finally, the man responsible for the whole job carries out a very careful last-minute inspection.

Before the final closing of the top part, hook-bolt spaces are filled in and rammed up (vents in the top core can usually be arranged through the hook-bolt spaces with vent tubes, as in the one shown at P, Fig. 8.68). The tubes are pushed down into the coke layer of the core and rammed in place; they are permitted to extend a few inches above the top face of the mould and their open ends are packed lightly with soft paper or rags.

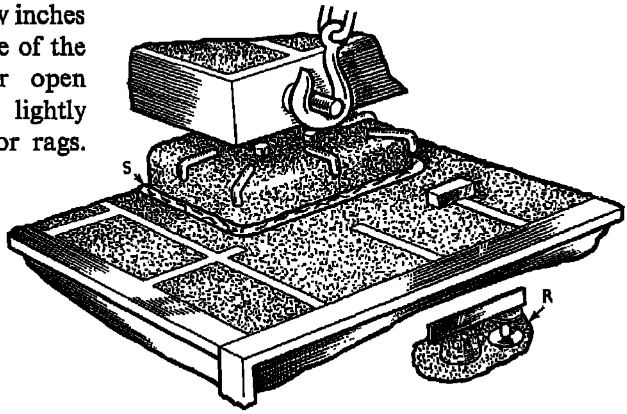


FIG. 8.70. *Use of soft clay "sausages" to show space left for metal after trial closing of mould.*

By closing the ends of vent-tubes in this manner, they are less likely to become choked by loose sand, which sometimes can happen when making up the runner-box or feeder-head boxes. Wherever possible, the temporary closing of the vents should be carried out before closing the mould.

POURING BOXES

Fig. 8.71 shows a cut-away corner section of a dried, ganister-lined runner-box, T, used for such moulds. The loam-covered and dried stoppers over the main downgate and the emergency inlet or "livener" are held down to prevent the metal from floating them out of position. When provided with suitable levers (bars), these provide a lift-out control, shown at U and V. A bottom-face loam-cake at X, and also a loam-covered skimmer-plate (when preferred) at Y (broken line) are shown. Lids are placed on riser and feeder boxes, W, and these are plastered around with loam at the joint, Z. This precaution will prevent the boxes from "drawing air" (a moulder's appellation) as otherwise an open riser will suck air through mould and core faces when the mould is poured. A properly sealed and well closed mould will drive internal (expanded) air and gas through the proper channels, instead of creating a "rush-out-vortex" through open riser or feeder-head boxes.

As with the bottom-part, the one man responsible for the job checks underneath the top-part of the mould before this is lifted and finally closed. If bolts and nuts, or cramps and steel wedges are used, these should be tightened down in turn progressively. The separate hump top-box is then dealt with in similar fashion, Fig. 8.70. For this, rags, S, are counted and pushed into the open spaces, clay rolls and "blobs" are put into place, and one try-on is usually enough to confirm correctness of section sizes (and chaplet sizes, when the latter are used). As cramps and wedges cannot be used on this box, wedges should be lightly tapped

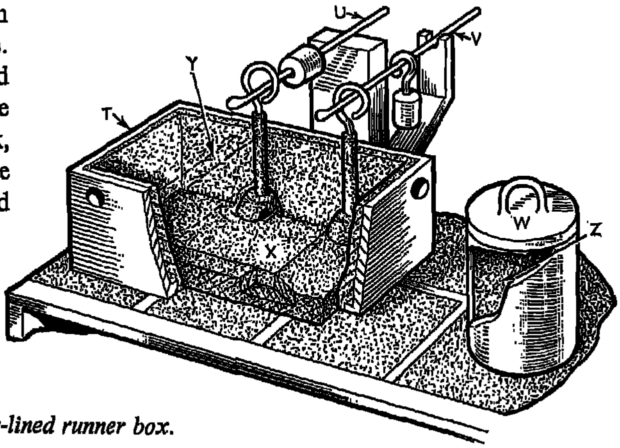


FIG. 8.71. *Ganister-lined runner box.*

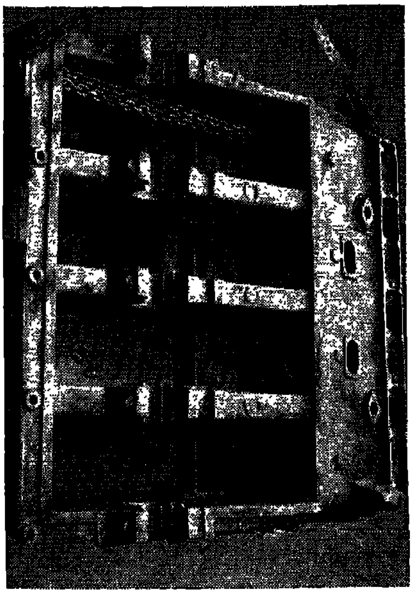


FIG. 8.72. *Finished and fettled crank-case casting.*

between any box-bar edges which do not quite come together, before placing a substantial weight on for the purpose of holding the box down.

The fettled and finished casting from such a mould as that described is shown in Fig. 8.72, in this some of the details mentioned and illustrated in the cut-away sketches will be readily identified. Adapting as a routine the stages outlined as standard for heavy work will result in the production of castings that will give full satisfaction to the engineer, machinist, foundryman and pattern-maker when set up on the marking-out table. When poured with metal at the correct temperature for the job and at a proper speed of running, such castings will not "weep" around the sites of chaplets, even under sustained hydraulic pressure.

PIT MOULDING

Engineering companies which specialize in heavy work and whose line of manufacture requires castings of most complex design and of the largest sizes, usually possess "tied" foundries, staffed and equipped to deal with almost all of their own designs of castings. Experience in working with the size of moulds and weight of metal necessary for these huge one-piece castings has usually been acquired over long periods of moulding and melting practice. Nevertheless, a high degree of risk from many sources is inseparable from the start to the finish of such work; it is watched for and reactions to it are controlled. Errors in practice or judgment can be dangerous and costly, and pit moulding is chosen for such work in many cases, to remove or minimize some of the inherent risks.

Pit moulds have been constructed for steel castings weighing as much as 200 tons, and the reader may visualize the expansion rate and the volume and pressure of gas generated internally, when such a mould is filled with over 200 tons of metal in a matter of minutes. Foundries catering

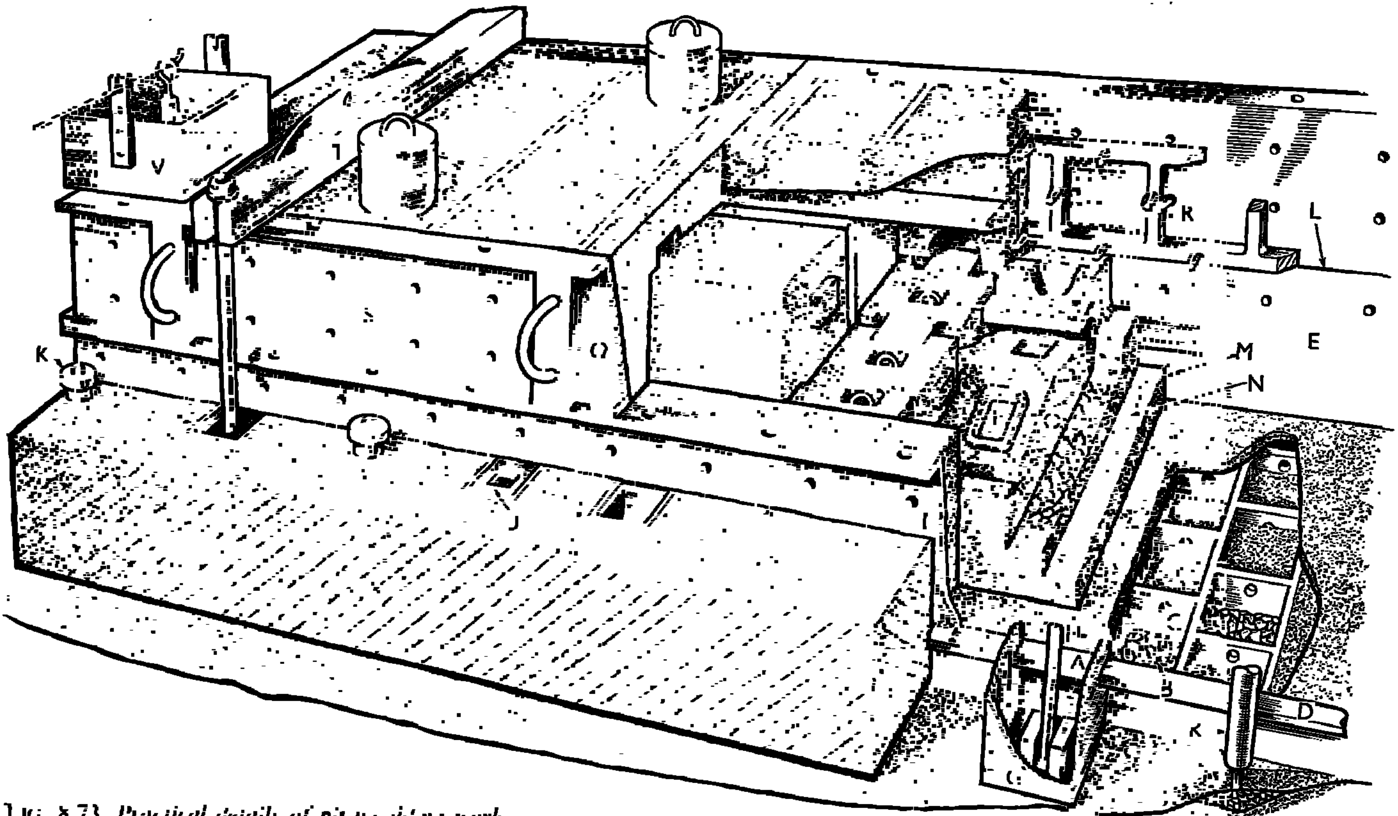


FIG. 8.73. *Practical details of pit-moulding work.*

for such heavy work are comparatively few, although the actual moulding side is often in itself a relatively small part of the job. Metal melting-rate and total capacity for molten-metal production and storage, also the crane and other equipment for lifting, place limitations on all but the few foundries competent to handle such work.

There is, however, quite a number of moulding shops equipped to make castings up to 40 tons in weight as a matter of routine. In most cases, these heavy jobs are made in permanent pits, for reasons usually associated with the particular foundry—it may be that the mould is larger than the foundry's stoving capacity, or no safe and suitable moulding box is available.

For pit moulding, early consideration needs to be given to the type of pattern to adopt. As the job cannot be rolled over, "bedding-in" or "bedding-on" of the pattern to a level bottom face in the pit is the alternative. For many machine-tool castings of substantial length, however, camber is initially put on to the bottom face of the mould. Then, on cooling, the heavy-section concave base-pieces straighten out to yield a level plane when cold. In all cases, however, the heavy pattern is lowered on to a prepared bottom mould-face in the pit, which is usually strickled to accommodate pattern shape. Thereafter, the details of the subsequent moulding and reinforcement are practically the same as for the heavy-box moulding routine already described.

Fig. 8.73 shows much of the standard practice for pit-moulded work, which to simplify description is compiled for the production of a housing casting *en bloc*. In its essentials, a moulding pit is a suitably planned large moulding box let down into the shop floor, in such a position as to be easily serviced by cranes, etc. First, a rectangular area of the foundry floor is excavated to the depth required. Cross-beams, A, are first laid in, and checked for level. A bed of small coke approximately 6 in. deep is then hard rammed over the bottom area up to the level of the beams, as at B. The bottom drag box, C, is then laid firmly on the beams and the coke bed and a course or two of hard-rammed sand follows, which brings this layer up to the drag joint-level, D. The pit box, E, is then lowered on to the drag and bolted securely to it, as at F. Boxes, G, roomy at their base, are placed in position on the cross-beams, with ample clearance being provided beneath the cross-beam slots to permit tie-bars, H, to be inserted easily into the slots. Loose lids (one shown at J) are employed to keep the sand out when the boxes are not in use. Vent-outlet tubes are placed at intervals, as at K, both outside and in the main coke-bed; all bottom vent outlets are taken into this bed. The space outside the box is then filled in and rammed up to floor level and the pit is ready for use. In many cases, permanent pits are brick lined, or (when water seepage is a problem) concrete lined and "proofed." In all these, permanent and substantial anchors are provided for the holding-down of tie-bars.

Patterns for pit moulding vary much in depth and may be of the split type, one-piece or skeleton made. In either case, they must be so positioned as to bring their joint-line to suit the top box-part, and the pit box joint-line at L. In the example shown, the bottom mould-face has to be lifted to suit the shallower-than-the-pit pattern, and a second layer of coke is thus necessary a few inches below the pattern bottom-face, as shown at M. This venting layer is of course connected down to the main coke layer, at B. Next, to bring the pattern up to the required level, one or more courses of hard-rammed sand are put in, as at N. The mould bottom-face is then swept over its full length with a strickle to match the pattern face, O; one or two separate frames for the "windows," P, are bedded in, this usually being done to the patternmaker's instructions to ensure correctness of position. In the case cited, the half-pattern is next lowered on to the strickled face. As this mould is open at both ends, the trial placings for checking purposes can be done repeatedly, a stake or two at each end serving to position the pattern without risk of damage to the mould face.

With the pattern finally in place, the ramming up of the mould body is carried out in the usual way, any "drawbacks," "lift-outs," "step-downs" and so on being worked into the routine as they come along. To reduce deadweight lifting or for other reasons, two or more top box-parts are sometimes planned, by using a sloping mould joint, as shown for instance at Q. Heavy top-sections of sand, which cannot be left behind and lifted out separately, have to be safely carried in the top mould; for these, the use of side grates or grids, as at R, bolted to the box sides, is the usual method employed.

SPECIAL PRECAUTIONS IN PIT MOULDING

Several depths and styles of top box-parts are obviously necessary to suit different designs of castings made in the pit, in order to economize in ramming time, deadweight lifting, and the like. Many of these boxes are built up and incorporate movable box-bars. All box-parts for heavy foundrywork, whether one piece or built up, must be so designed as to carry an ample factor of safety when it comes to lifting and manoeuvring and this proviso applies likewise, of course, to hooks, staples and other details. Rows of spaced holes to a chosen pattern can be arranged to match in mating components for fixing purposes when making side- or core-grates, as also can many other details which require a convenient hole in the box-part.

The first-on (and last-off) section of the top mould-part, S, Fig. 8.73

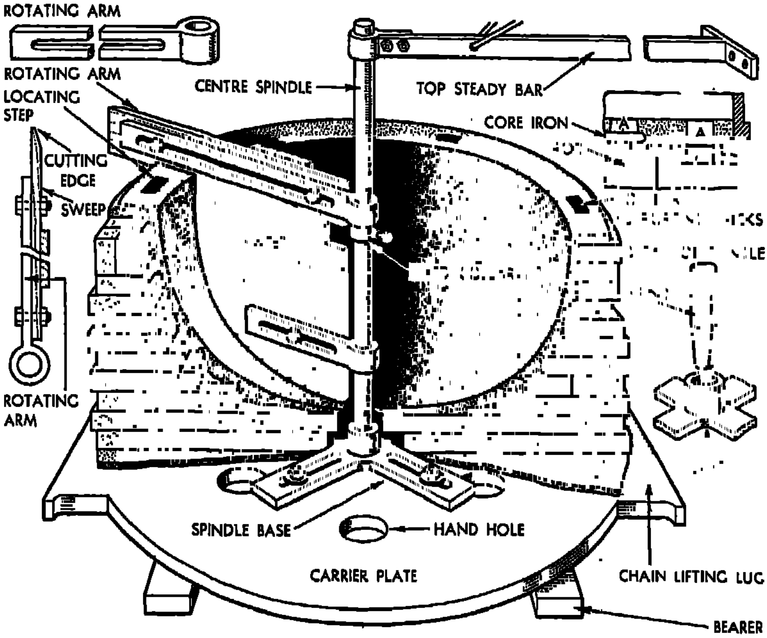


FIG. 8.74. *Construction of a loam-moulding pit.*

shows the cross-beam T bolted in position; for shallower box-parts, the cross-beams can be raised on bricks or iron blocks to suit the tie-bars to be employed. A ganister-lined runner box, V, can be easily placed in position, with a round bar inserted through the holes in the brackets for the purpose of manipulating the runner stoppers.

Nowadays, the drying of pit moulds is most efficiently done at controllable temperature by the employment of portable forced-draught driers which operate without any attention when once commissioned. These modern oil- or gas-fired or electric units will quickly evaporate mould moisture, and harden "synthetic" sands to a bone-dry condition. They represent a most worthwhile advance to eliminate the "blown ash" and uncertain temperatures associated with the older coke-fired variety, which require an operator with experience only acquired after long practice.

LOAM MOULDING

Loam moulding is a specialized branch of foundrywork. It is still extensively used, however, to produce any regular internal, or external, circular, or other symmetrically-shaped casting that can be "swept up" with one or more strickles, or skeleton formers, and where the economy

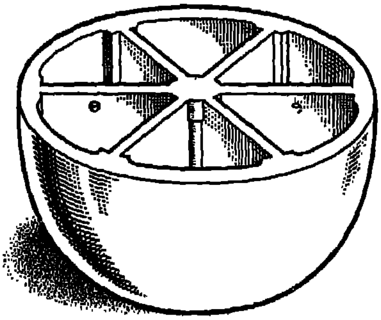


FIG. 8.75. *Typical heavy casting produced by the loam-moulding method.*

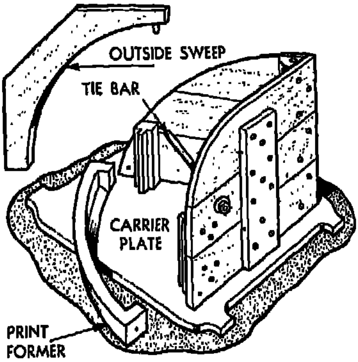


FIG. 8.76. *Core-box producing segment cores for loam moulding.*

of pattern work makes the method attractive. This is particularly so in heavy industry for many sizeable castings, such as turbines, rotors, propellers, pipe-bends, spiral rope-winding drums, and countless other designs. Patterns such as would be used for the rammed-up moulding methods are replaced by sweeps, strickles, templets and formers to produce the casting shape. For the really heavy jobs, a mass of cast-iron equipment is sometimes necessary, ranging from thick-section baseplates and large-diameter spindles, etc., to ensure rigidity at all stages during the "build-up" of the mould with bricks, laid to within inches of the movable sweep board.

LOAM MIXTURES AND APPLICATION

Loam-moulding refractory mixtures for forming into the casting

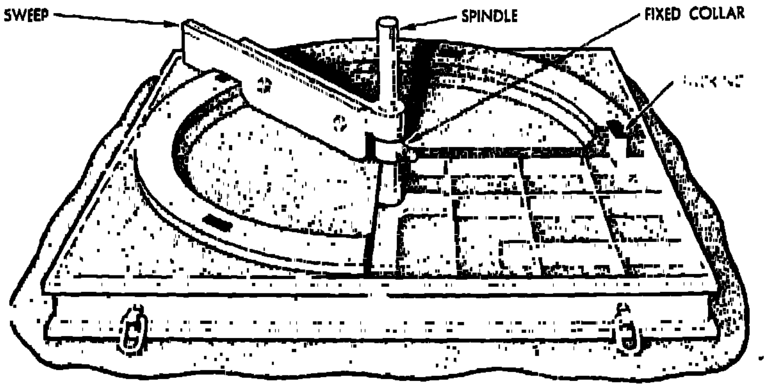
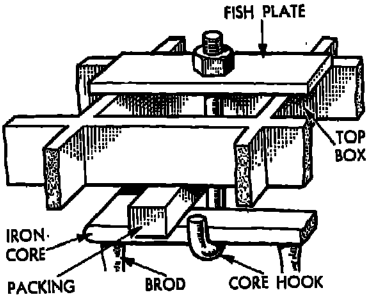
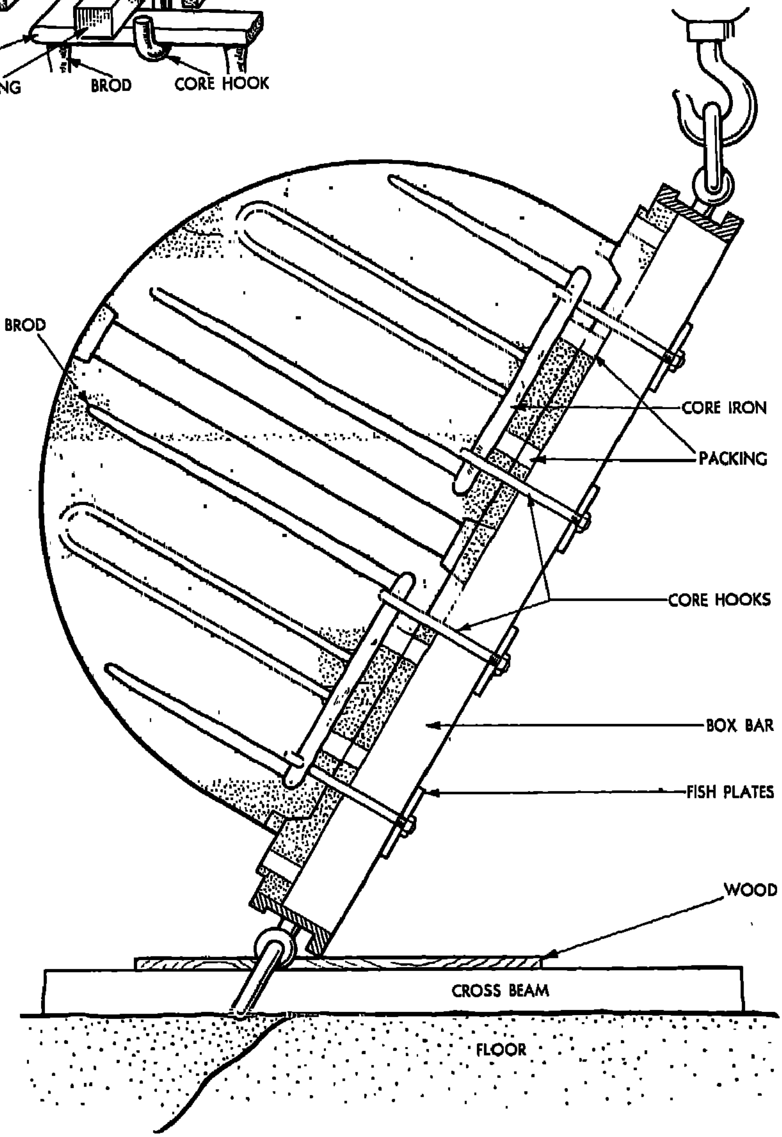


FIG. 8.77. *Cope part of a loam mould being swept to shape with a strickle.*



(Below) FIG. 8.78. *Cope with six segment cores positioned in drag part.*

(Left) FIG. 8.79. *Method of securing segment pieces to cope part.*



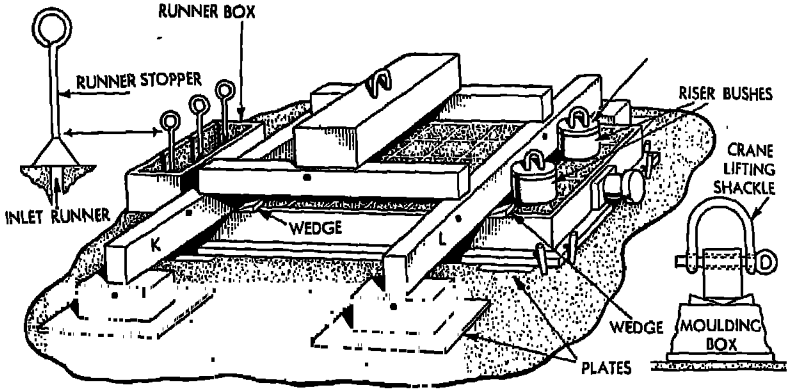


FIG. 8.80. *Mould weighted down ready for casting. Note wedges to ensure that bearer bars (K and L) are making proper contact.*

shape are usually of quarried sand ground with water and bonding material in a mortar-type mill. They vary in consistency as delivered to the moulder from a "stiffish" highly (natural) bonded paste, to a flow-on slurry for use in making a finishing coat on the mould. Fig. 8.74 illustrates the basic method and much detail associated with loam moulding. With all such jobs, rigidity, strength and freedom from whip are most essential, as many loam-mould constructions are lifted and transferred to a stove for drying. For those dried *in situ*, or too heavy to move, the same rules are also necessary. The 10-ton boiler-end press-block shown in Fig. 8.75 is a typical example of the making of a swept-up loam outer mould-part, and a strickled-up sand face from a skeleton-framed corebox for making a repeating segment-core for the inside. One of the core-grates is shown in Fig. 8.76; these are handled in the same manner as shown in Fig. 8.61.

The strickled face of the top-part of the mould is shown in Fig. 8.77; after this is dried, it forms the base for the six segmental cores, which are placed symmetrically in position and securely held, as shown in Figs. 8.78 and 8.79. After rolling the job over, it is lowered on to the bottom half-mould, and checked for metal thickness. An outer box is often employed with jobs cast at or above floor-level; any available moulding box that will pass over the bottom-half is rammed up in the manner shown to serve as an extra precaution against run-outs when pouring heavy-section castings. Where holding-down weights are considered too heavy for a built-up loam mould, it is either lowered into, or constructed in a pit, being then rammed up in the manner shown in Fig. 8.80.

Chapter 9

CORES AND COREMAKING

CORES are those parts of a mould which, in order to produce a required casting, have to be made as separate sand shapes. These sand shapes, or cores, are assembled and inserted into the mould in such a way that they form internal shapes, undercut contours or isolated hollow pockets in the finished casting. To produce a casting such as the one shown in Figs. 9.1 and 9.2 it is necessary first to have a pattern (Fig. 9.3) from which can be made two half-moulds (Fig. 9.4); if these two moulds were put together and metal poured in, a solid casting would result. This is obviated by inserting a core in the mould (see Fig. 9.5), and thus, a hollow casting is produced. In order that the core may be located correctly in the mould it is essential that some form of seating be provided. This seating is allowed for in the pattern, and is called a core print.

A core box (Figs. 9.6 and 9.7) should be made which will produce a core corresponding to the two prints on the pattern and the circular hollow section of the casting. The core box consists of two separate half-blocks into which is cut the shape of the core (Fig. 9.8). Each half-core box is then filled with sand and should be rammed firmly and evenly. A reinforcing wire may be placed in the core, as explained later in this chapter. The two halves of the box are then closed together—locating dowels ensuring correct matching. The open ends of the core are finished off by ramming, tucking, and making firm. The sand thus rammed into the core box becomes a compact mass of the required shape. This sand shape, or core, must now be withdrawn from the core box and so treated that it can be handled, placed in the mould and fulfil its function in providing a hollow casting.

The treatment of the core depends on the nature and type of sand used. The majority of sands require that the core be dried, or baked, at a temperature of 520 deg. F., for a period of time from 1½ to 4 hours according to the size of the core. After baking the sand becomes hard and capable of being handled. The core is then placed in the bottom half of the mould that has been prepared from the pattern (Fig. 9.5). The top half of the mould is then placed in position. Molten metal is poured through predetermined runners into the cavity between mould and core, thus forming the required casting. When cool, the casting is removed from the mould and the sand core displaced. The casting is then ready for fettling, this process being described in Chapter 12.

REQUIREMENTS OF COREMAKING

Coremaking is the art of producing cores which are an exact reproduction of the internal shape of a core box. Cores must be so formed that when assembled in a suitable mould they will allow liquid metal to be poured over and around their shape. The metal must flow smoothly and without agitation. The core must resist the erosion of the metal and allow that every cavity of the core and mould be filled with metal. Cores must resist the heat of the metal and must maintain their shape without breakage or distortion long enough to allow the liquid metal to solidify, but as soon as the metal begins to contract on solidification, then the core must allow this contraction. The solidification of the metal and the partial disintegration of the core must proceed simultaneously. The resultant casting must have been so able to contract that no undue strains or cracks are formed.

The final requirement is that the core should be capable of removal from the casting with the minimum of effort and without damage or distortion of the casting. The design of the majority of castings is such that cores are necessary in some form or other. The art of the coremaker in producing cores that will, in turn, help to produce good castings is an essential part of modern foundry practice.

The principles of coremaking are the same, whether applied to iron, steel, or non-ferrous foundry practice. A coremaker should be able to make cores to suit any section of the foundry industry. The materials with which he works must be controlled and varied to suit the metal which is to be used. For instance, cores which are to produce a steel casting must be much stronger in every way than those which are used in the making of aluminium castings. When making cores for different branches of the foundry industry, the following points govern technique:

(1) Temperature at which the metal is to be poured,
(2) Weight and consequent lifting power of the metal,
(3) Fluidity of the metal,
(4) Chemical analysis—gas absorption.

The use of cores has been vastly increased with the development of the modern internal combustion engine. Designers and engineers call for castings more intricate in design and possessing jacketing for fluid cooling systems. The modern mechanized foundry engaged on general engineering castings, must possess a core shop at least equal in size to its moulding section. In the case of mechanized production of moulds, cores are required in large quantities. The time taken to produce these cores is

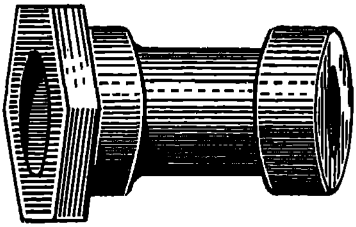


FIG. 9.1. *A simple type of casting requiring the use of a core, which is inserted in the centre of the mould.*

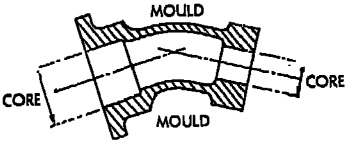


FIG. 9.2. *Sectional view of the casting in Fig. 9.1.*

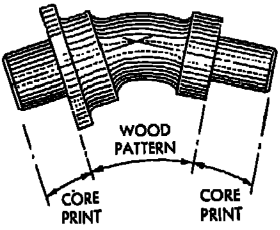


FIG. 9.3. *Half-pattern for production of the casting in Fig. 9.1.*

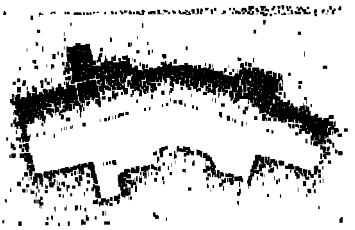


FIG. 9.4. *The impression of the pattern in the sand, forming a half-mould.*

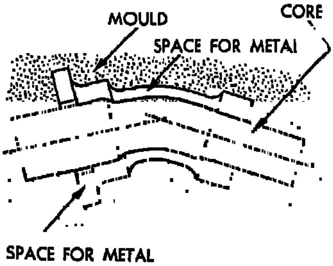


FIG. 9.5. *Details of the half-mould with the core placed in position.*

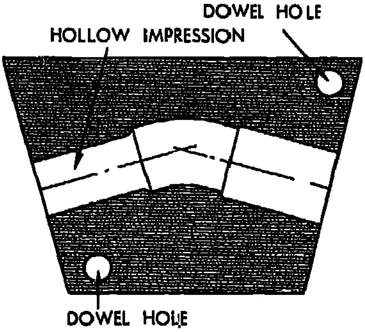


FIG. 9.6. *Half-core box for production of the core shown in Fig. 9.8.*

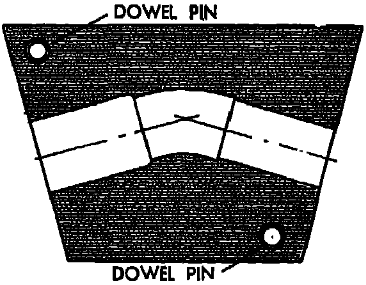


FIG. 9.7. *Other half of the core box.*

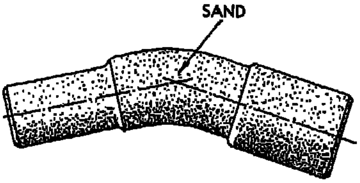


FIG. 9.8. *The core required for the casting shown in Fig. 9.1.*

much greater than the time taken to produce the mould into which they fit. This applies particularly when the castings are small, the cores intricate and require a number of cores for each casting.

SAND FOUNDRY PRACTICE

In sand foundry practice, as the name implies, cores are made from various types of sand. Owing to the nature of sand extreme care must be taken to ensure that the core will fulfil all its required functions—these will be detailed later. Only certain types of sand can be used for coremaking; furthermore, the sand must possess the following main qualities:

(1) *Green Bond or Green Strength.* This is the bond which the sand possesses when green or in its undried or natural state. Green bond is the power of the sand to hold together and maintain any shape into which the core may be formed. Green bond enables a core to maintain its shape after it has been withdrawn from the core box.

(2) *Dry Bond or Dry Strength.* This is the strength which exists after the core has been allowed to remain in the core oven for a suitable time at a temperature of 500 to 520 deg. F. This operation is referred to by some foundrymen as baking, while others refer to the core being dried.

(3) *Permeability.* A core sand must possess permeability in order that gases generated during casting may obtain quick exit to the atmosphere. Vents, or passages, are formed in the cores by the coremaker, but the sand between the face of the core and the vent passage must be such that the gases are allowed quick entry into the vents.

(4) *Ease of Collapse After Casting.* This means that it must not be incapable of freely separating after casting. The fact that every trace of sand must be removed from intricate internal jackets, without undue treatment of the casting, has been responsible for the development of the core sand as used in the modern foundry.

Development of the core shop during the last twenty years has been to find, operate, and improve a sand which would fulfil the requirements as outlined. Different branches of the industry have developed along varying lines, but the practice of using an oil-bonded silica sand has, in most foundries, now become almost universal.

CORE-SAND PRACTICE

Core-sand consists of a silica sand to which bonding materials have been added. A silica sand is chosen for coremaking because of its quality of easy disintegration after casting. Core-sand practice consists of adding to a silica sand materials which will create and control green bond and dry strength. Green bond is formed in a silica sand by the addition of some form of gum. Dextrin, a material made from starch products, when

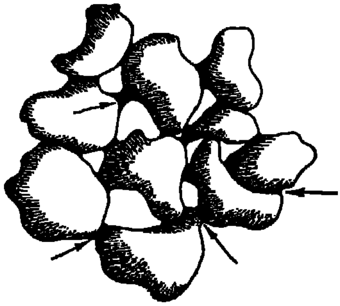


FIG. 9.9. *Capillary action of linseed oil, forming attachments between the grains of sand (shown by the arrows).*

added to moist silica sand creates green bond. This green bond is formed by the action of the dextrin and water mixing into a gum and spreading itself over the grains of silica sand. Each grain of sand tends to stick to its neighbour; thus in a mass of sand green bond is formed.

Dry strength is added to a silica sand by the use of an oxidizing oil. Linseed oil is most commonly used for this operation. Linseed oil, when added to the silica sand, mixes thoroughly and easily, and covers each sand grain with a film of oil. The baking operation through which core-sand has to pass oxidizes this film of oil on each sand particle and causes it to become a hard film, joining together adjacent grains of sand. Capillary action takes place as shown in Fig. 9.9. The linseed oil, surrounding each grain of sand, is drawn to the point of contact between two grains of sand. As this hardens it forms a connexion between the two grains of sand; it does not, however, completely fill the space between the two grains of sand; the particles, therefore, hold together securely but air passages will exist.

The simple mixing of core-sand is 1 cwt. of silica sand (dry), 2 lb. of dextrin, 1 pt. of linseed oil, and 2 pt. of water. In the early stages of core-sand practice it was soon realized that a compound of the above materials could be manufactured and supplied to the coremaker ready mixed for use. This practice has developed extensively, and numerous types of compound have been made available to the foundry industry, each having its advantages and limitations. Points to note when selecting a good core-sand are that it must be capable of retaining its working life, it must not air dry whilst it is in use by the coremaker, and it must not become lacking in green bond. Core compound manufacturers have made various additions to their products to control this feature. Such materials as molasses, mineral oil and ammonium nitrate are in use. Atmospheric conditions have a pronounced effect on the workability of an oil-sand, and they can either help or hinder the air-drying quality.

To satisfy different types of coremaking which have to meet the demands of the making of cores for various metals, compound manufacturers have evolved varying compounds which govern the quality of both green and dry strength. These vary from a thick viscous material, classed as a semi-solid compound, to a thin material which is called a core cream. Core compound consists of dextrin, water, linseed oil with the

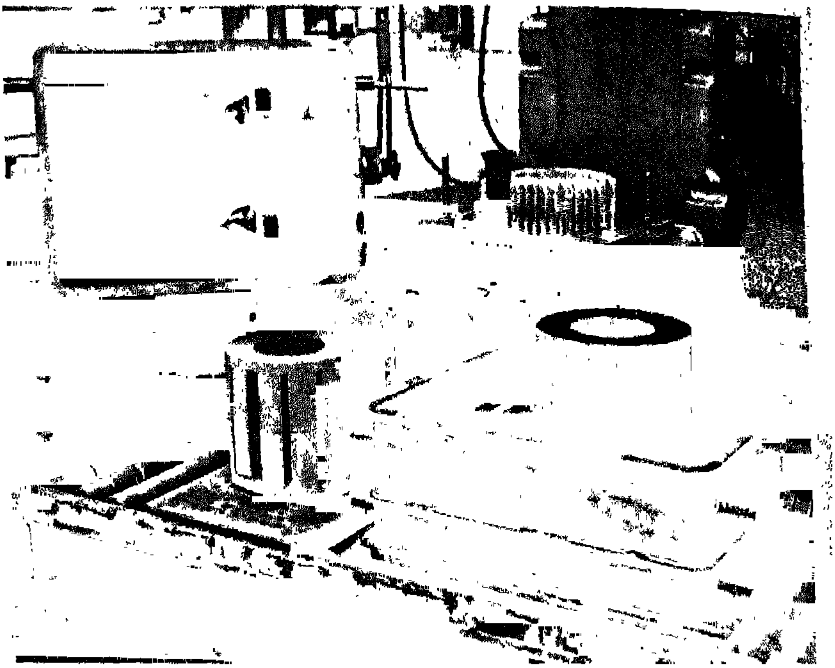


FIG. 9.10. *Shell cores rammed-up in top half-mould for electric-motor stator body.*

addition of molasses, a mineral oil and various chemicals designed to control the air-drying factor. To operate a core compound satisfactorily, the foundryman has to start with a dry silica sand. This sand, in its natural state, carries a moisture content varying from 3 to 6 per cent.

Linseed oil is the main oxidizing oil, to which can be added such materials as resin or pitch. Substitutes are used such as soya bean oil, cotton seed oil, and any readily oxidizing oil. When used alone, linseed oil will permit a dry strength in a silica sand, but will not produce any green bond whatsoever. Dextrin, or any of the starch materials, will produce a green bond but not dry strength. Core-sand practice utilizes these two features, and according to the method of manufacture (that is, machine, or hand, or blown core) the amounts of each constituent are graded. A core which is to be made by a core-blowing machine (see Chapter 10) is provided with a shaped dryer or support after it is turned out of the core box. The core, therefore, does not require green bond in any great strength. A core will blow much more easily when the green bond is low. A point requiring emphasis is that green bond and dry strength of a core-sand can be controlled between wide limits. These limits cover the material being cast, the size and shape of the core and the method of manufacture.

RESIN BONDED CORE-SAND

During recent years considerable progress has been made in the application of resins as a bonding material for core-sands. The properties of the resin are such that when 1 to 2 per cent of liquid phenolic resin is added to a dry silica sand, together with a green-sand bonding agent, a core-sand is produced which meets the requirements of the core shop. It will ram easily, and on baking will give a core of satisfactory strength for casting. The advantages of resin are that a quicker drying time is made possible. Green bond in such resin core-sand is obtained by the use of a cereal binder and the addition of 2 to 3 per cent water necessary to develop the cereal bond.

SHELL AND CO_2 CORES

Recent practice in the core shop has developed around the use of shell cores. The shell-moulding process is described in detail in a later chapter. Here, we shall mention briefly the application of shell cores in the foundry industry. Fig. 9.10 shows a casting of an electric-motor stator body, a section of which necessitates the use of a core. In this instance a shell core is used, and the core is made as shown in Fig. 9.11. The method of making a shell core consists of applying a parting agent to the face of a metal core box which has been heated to a temperature of 200 deg. C. The resin-sand mixture

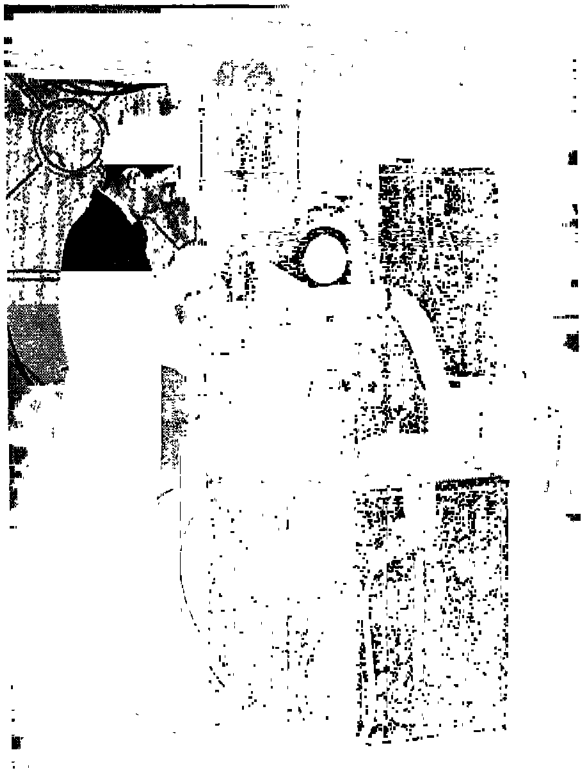
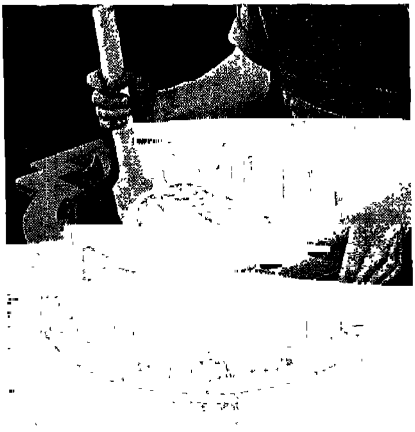


FIG. 9.11. *Semi-automatic core-making machine for producing resin-bonded shell cores.*

is then either blown or fed by gravity into the core box. The effect of the hot core box is to invest or partially cure the resin in the mixture, forming a shell of bonded sand immediately adjacent to all the hot surfaces of the core box. After a time of approximately 30 seconds, the core box is reversed and the sand that has not become part of the shell is poured or removed by gravity or by suction from the centre. The core box, with the partly cured shell, has then to be placed in a heating oven for approximately 2 minutes to complete the curing of the resin and to give a hard baked core. This core is very easily removed from the core box. Some cores, however, may require ejection from the box by a series of ejector pins.

Another recent technique, dealt with in more detail in a later chapter, is the CO_2 process. Using this technique, a core sufficiently hard to withstand casting temperatures has been developed by the use of sodium silicate, 3 to 4 per cent by weight, added to a dry silica sand, together with ½ to 1 per cent of a suitable organic material such as pitch, wood-flour or coal-dust. The bonded mixture is suitably rammed by hand (Fig. 9.12), or the core may be blown by machine. Carbon dioxide (CO_2) is passed through the core, a process known as "gassing the core" (Fig. 9.13). The effect of the carbon dioxide is to react with the sodium silicate, causing a hardening of the sand which ensures that the core, on withdrawal from the box, is capable of being handled, stored or passed to the mould, and will resist the flow of molten metal. Easy breakdown of the



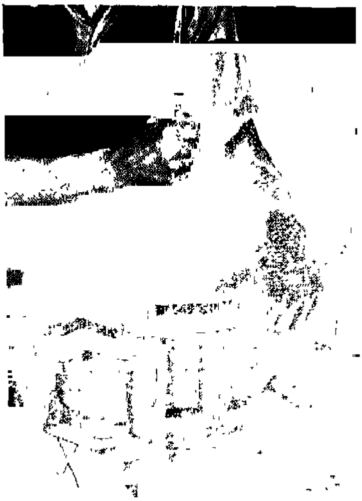


FIG. 9.12. *Hand-ramming a core with sodium silicate mixture for "gassing" with carbon dioxide gas.* (Right) FIG. 9.13. *"Gassing the core" with carbon dioxide through a rubber pad held over a hole in the hood.*

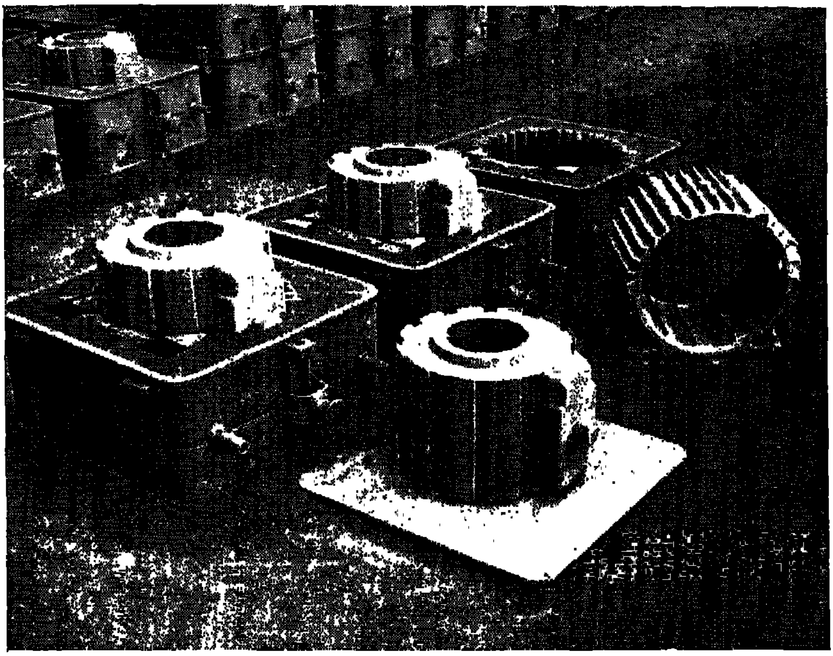


FIG. 9.14. *Two CO_2 cores in the mould. In the foreground is a core of the same pattern, and on the right is a casting produced from one of these moulds.*

core in this process is assured by the use of the organic materials. Fig. 9.14 shows some CO_2 cores in the mould.

AIR-DRYING RESINS

The development of resins in the foundry industry has produced in the core shop a range of materials which give accelerated drying with the advantage of avoidance of distortion of cores when in a green-sand state. The use of a mixture of sand to which has been added liquid resins, together with an accelerator or hardener for such resins, enables a core to be made, and after a suitable time the core-sand becomes hard in the core box. The advantages of this system are particularly attractive when dealing with cores such as illustrated in Fig. 9.15, which shows a core assembly. Distortion or sagging of a green-sand core can only be avoided in normal foundry practice by the excessive use of core iron supports, etc., and there is great advantage to be gained from a sand which dries in the box. Such air-drying again avoids the use of core driers and the necessity for a core to be made in halves in order to overcome sagging problems.

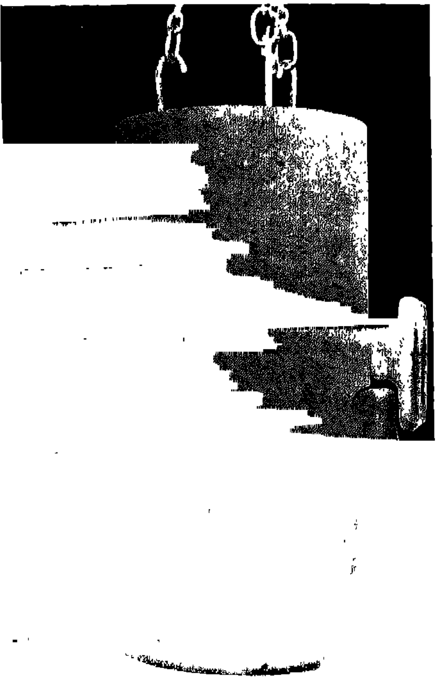


FIG. 9.15. *An elaborate core assembly made self-supporting by the use of air-drying resin mixed with the core-sand.*

MIXING MACHINES FOR CORE-SAND

Core-sand cannot be mixed satisfactorily by hand, therefore mechanical means have to be resorted to. The main types of machine are as follows:

(1) roller mill, as used for moulding sand;

(2) core-sand mixer, of the vertical revolving-arm type;

(3) core-sand mixer, of the horizontal paddle type.

Fig. 9.16 illustrates the normal type of roller mill as used for core-sand. The rollers, or mullers, should be set to operate 1 in. clear of the bottom of the mill. When core-sand is mixed in a roller-type mill, "chequer" plating is used to form the pan lining. The rolling action of the mullers and the turning-over action caused by the ploughs ensure thorough mixing and maximum green bond. A roller mill is suitable for core-sand when a cereal binder, or a thin liquid compound, is to be used.

Figs. 9.17 and 9.18 show alternative types of vertical revolving-arm type of core sand-mixer. These machines have been developed exclusively for the

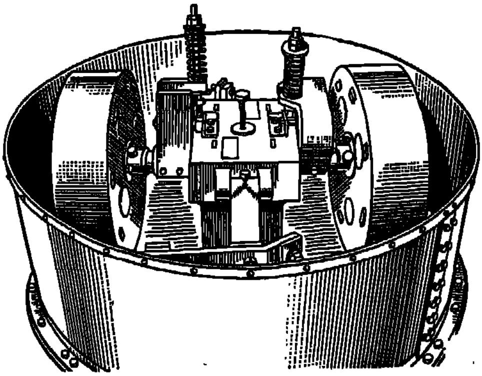


FIG. 9.16. *Roller mill for mixing core-sand.*

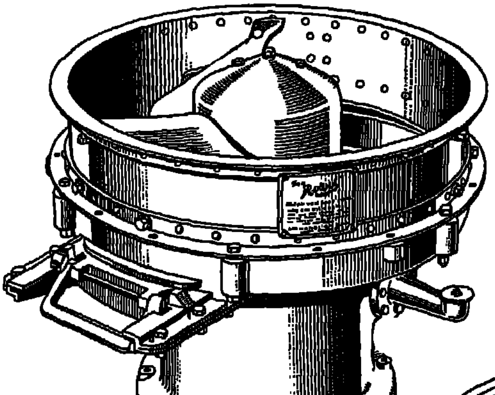
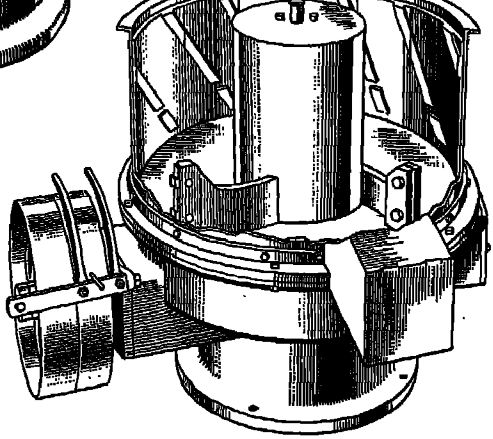


FIG. 9.17. *A vertical revolving-arm mixer for core-sand.*

(Below) FIG. 9.18. *Another type of revolving-arm mixer for core-sand.*



mixing of core-sand, and they perform the mixing operation in an efficient and thorough manner. As the revolving arms pass below the fixed arms an intensive mixing operation is caused.

This type of mixer ensures complete mixing of any type of core-binder compound or cereal in a period of 5 to 7 min.

Figs. 9.19 and 9.20 show alternative types of paddle mixers. These machines are made in all sizes for from 1 to 10 cwt. of sand mixed as a batch. It will be seen that this type of mixer, which is mechanically driven, consists of two shaped arms revolving in opposite directions, causing an intensive mixing operation among the contents of the mixer.

GREEN-SAND CORES

Cores in certain foundries engaged on production of thin section work may be made in green sand.

A green-sand core is used where the shape is such that a good bearing surface is obtained. A green-sand core is weak and will not stand any great erosion of the liquid metal. The use of a green-sand core is of a specialized nature, and is dependent on the condition peculiar to the mould in which the core is to be placed and the metal which is to be poured in that mould. The controlling factors are as follows:

(1) Size of core,
(2) Area of core prints,
(3) Shape of core, supports, etc.,
(4) Method of inserting core,
(5) Location of runner ingates,
(6) Venting arrangements.

The advantages of a green-sand core can, however, be summarized as follows:

(1) It will collapse more easily,
(2) Less gas is generated during casting,
(3) Easy removal of sand from casting,
(4) No stoving is required,
(5) Sand can be reused.

DRY-SAND AND LOAM CORES

Moulding sand suitably mixed, and with controlled addition, is used to make dry-sand cores. In a foundry not possessing facilities for making core-sand, dry-sand coremaking is normal practice. For certain work in a jobbing foundry core-sand may be considered too expensive to use on large cores. In these cases, core-sand must be mixed which will meet the condition imposed by the particular casting. The dry strength, obtained by baking, must allow handling and lifting of the core, and must resist the erosion of the metal. The sand must be controlled to guard against cracks in the core or scabs on the casting. Venting must be given careful attention. Dry-sand cores must not be rammed hard on the surface which comes in contact with the metal.

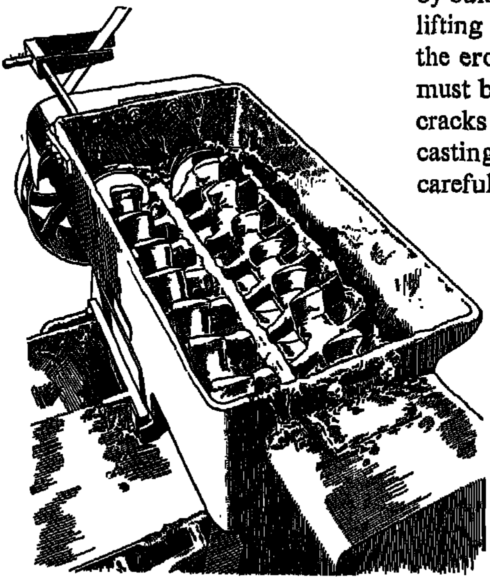


FIG. 9.19. *Mechanically-driven horizontal revolving-arm mixer for core-sand.*

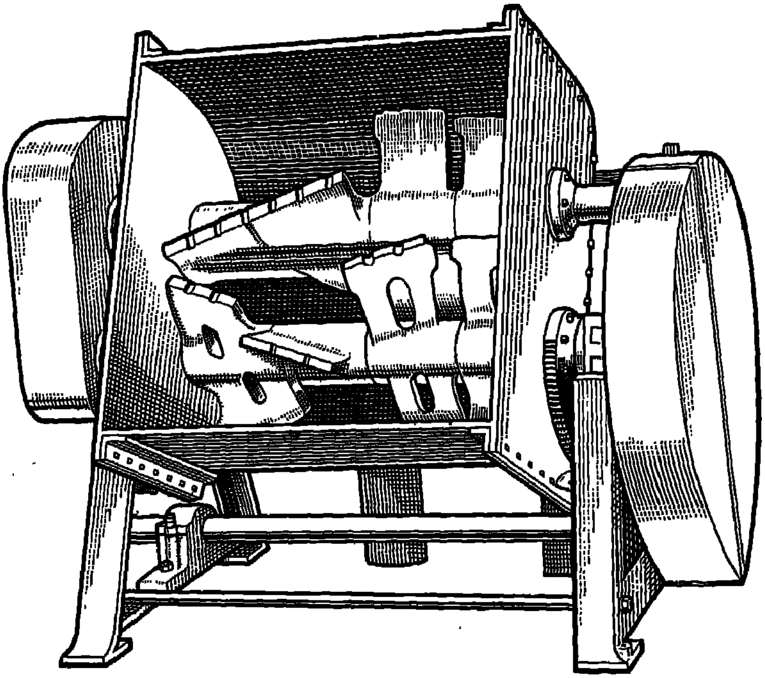


FIG. 9.20. *Another type of horizontal revolving-arm mixer for core-sand.*

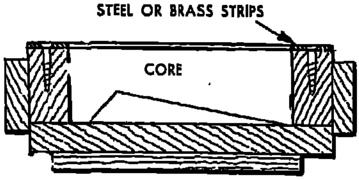
The principle of making a loam core is similar to that of making a loam mould. The process is fully described in Chapter 8.

CORE BOXES

Sand is the material with which the coremaker works, whereas core boxes are the means whereby the sand is worked into the required shape and becomes capable of carrying out its part in the production of a good casting. The design of a core box is of extreme importance, and hours of production effort may be lost due to small features which the patternmaker is liable to overlook or treat as unimportant. Liaison between the designer, patternmaker and foundryman is necessary if good production methods are to be employed. The introduction of a small undercut, or facing, may be the cause of complications in the core-box equipment, whereas the designer can help considerably by agreeing that this facing may be carried along to the base of the core box. A core box must be made of a material which will resist the abrasion of the sand during ramming, it must be light and durable, and must be strong enough to allow vibration or rapping to loosen the sand core prior to drawing off the box. Core boxes, which are required to produce only single castings and are not likely to be called on for repeat orders, are made in as simple a manner as is possible, and from a common wood. Pine is used for the majority of this type of core box.

The material and manufacture of a core box is entirely dependent on the number of cores that the box is expected to produce. Boxes from which only small quantities of cores are to be produced, but these small quantities repeated over a period of time, require to be made of a material that will not warp or crack in storage. Mahogany is the wood from which production, or semi-production, core boxes are usually made. A well-seasoned mahogany, when worked into the form of a core box will, if reasonably and correctly used, produce from 1,000 to 2,000 cores. The wear that takes place can be noted, and inserts of metal can be made. A mahogany box will wear at the open face of the box owing to abrasion of the sand when scraping off and levelling this face of the core. To prevent this wear taking place, steel or brass strips are inserted along the edges of the box, as shown in Fig. 9.21. These strips should be placed over the full width of the side of the box, as shown. The strip must be so let into the box that it will not loosen due to the rapping of the core.

Metal inserts are, normally, used in core boxes, and are made to form flanges, bosses, or ribs which tend to impede the ramming of the sand, and thus become worn owing to abrasion of the sand (see Figs. 9.22, 9.23 and 9.24). Mahogany core boxes, suitably steeled at the joints and carrying metal loose pieces at the points at which abrasion takes place, and suitably protected against misuse by rapping, will give trouble-free service for many thousands of cores. In the larger sizes of core boxes reinforcement by means of metal corner pieces and tiebolts is often necessary. For continuous production and for precision coremaking, metal core boxes are essential.



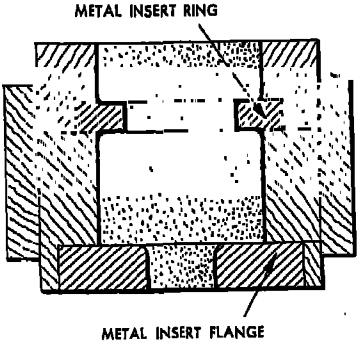
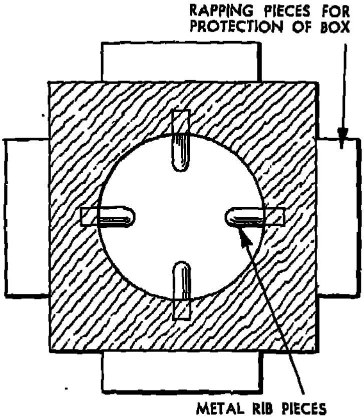


FIG. 9.21. *Section through a core box, showing metal wearing strips placed on top of the outside edges.* (Right) FIG. 9.22. *Sectional side view of the same core box, in which metal insert rings and flanges are used for protection against wear.*



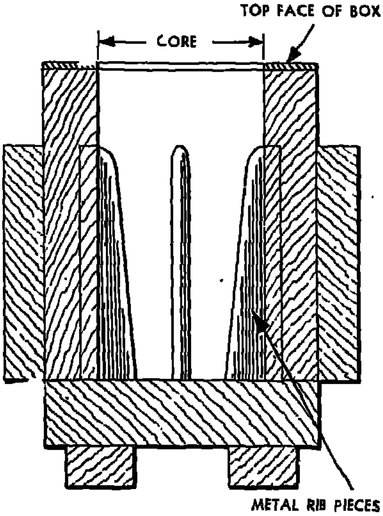


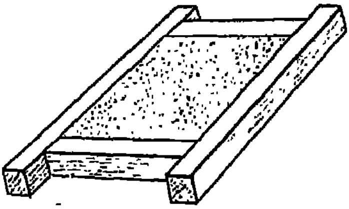
FIG. 9.23. *Plan view of a core box.* (Right) FIG. 9.24. *Section through the same core box showing how metal rib pieces are positioned.*

Metals used for core box construction are cast iron, aluminium, brass and malleable iron. Cast iron is the ideal metal from which a production core box should be made. A cast-iron box will not bend or distort, and resists the abrasive action of the ramming of the sand. In some instances, e.g., when a core-blowing machine is used, special alloy cast iron is utilized. Methods of surface hardening are employed to increase the erosion resistance. Chromium plating is used where the design of the box will allow. This has proved very successful in preventing wear on core boxes used for core blowing, owing to the hard nature of the chromium surface. The disadvantages of cast iron as a material for core box construction are its weight and its tendency to fracture on impact. By careful consideration of the weight factor and by skilful use of thin sections and strengthening ribs, cast iron can prove extremely valuable for the production of core boxes.

TYPES OF CORE BOXES

Core boxes may be divided into five main type classifications, and for each type simple rules of design and operation apply. These types are as follows:

(1) *Frame Type Core Box* (see Figs. 9.25 and 9.26). This is used when the number of cores required is small and not likely to be repeated. Two degrees of taper must be allowed as minimum for drawing away the frame from the core. The top side of the box must be clearly marked, otherwise the coremaker is liable to try and draw the box against the taper



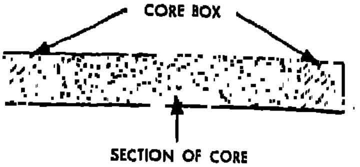
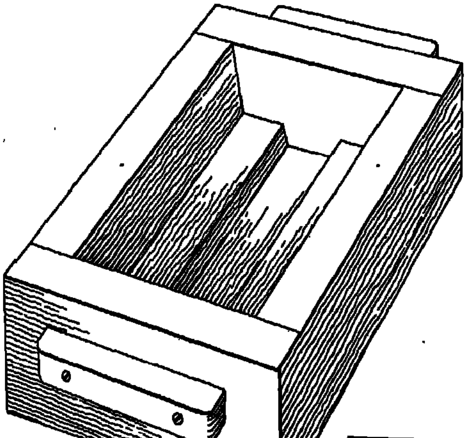
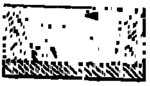


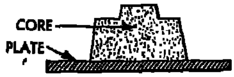
FIG. 9.25. *Simple frame-type core box.* (Right) FIG. 9.26. *Sectional view through the same core box.*

of the core. Finding that the core will not leave the box, more rapping is given to the box; consequently the core becomes undersize.

(2) *Plain Turnout or Knockout Box* (see Figs. 9.27–29). This is the most simple and most extensively used type of core box: it does not carry loose pieces or undercuts and consists of an open box with sides and base into which sand is rammed to form a core; the box is then turned over on to a core plate, the core box sitting on the core plate. The internal sides must be so constructed as to allow a minimum of 2 deg. taper; this should be maintained in order that the box may be withdrawn without disturbing the shape of the resulting core. This type of box requires the minimum amount of rapping, or vibration, before it is withdrawn. It is a common fault that the patternmaker does not allow adequate means of providing a grip for the coremaker during the operation of drawing off the core box. For production boxes it is important that a properly designed means of handling be placed in such a position on the core box that the coremaker knows that by using the handles provided, balanced control over the box during the withdrawing or stripping







(Left) FIG. 9.27. *Plain knock-out-type core box.* (Below left) FIG. 9.28. *Section through the same core box.* (Below right) FIG. 9.29. *Core from the same box.*

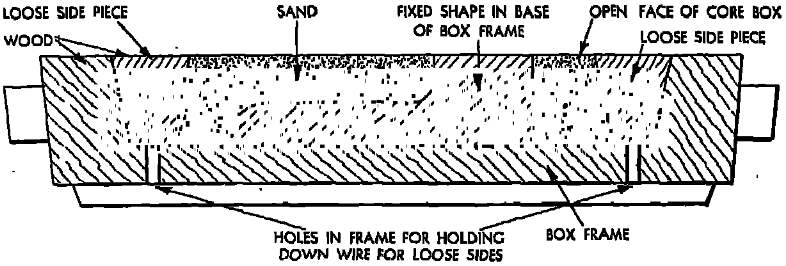

LOOSE SIDE PIECE
WOOD
SAND
FIXED SHAPE IN BASE OF BOX FRAME
OPEN FACE OF CORE BOX
LOOSE SIDE PIECE
HOLES IN FRAME FOR HOLDING DOWN WIRE FOR LOOSE SIDES
BOX FRAME

FIG. 9.30. *Section through turnout box with loose sides. The centre part of the box is fitted to the base.*

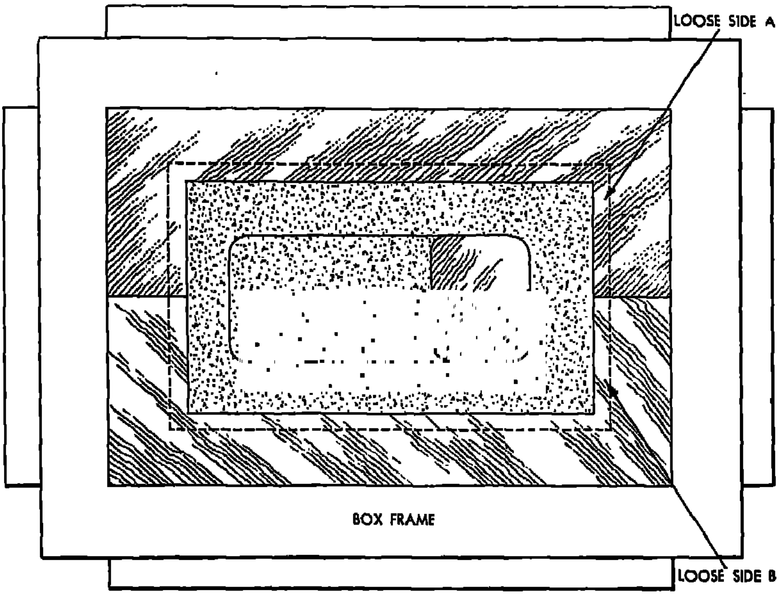


FIG. 9.31. *Plan view of the turnout box shown in Fig. 9.30.*

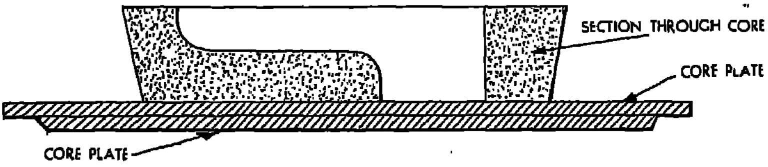


FIG. 9.32. *Core from turnout box drawn out on to the core plate.*

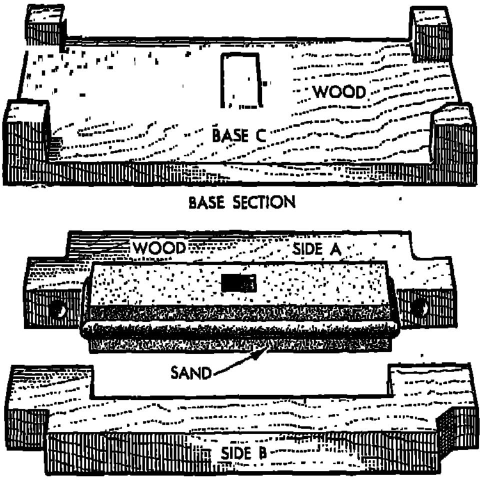
operation can be maintained. A plain turnout box is made when design of equipment is such that 2 to 4 deg. taper can be allowed on each side of the core box. On the base of the core box various contours, or shapes, may be fixed.

(3) *Turnout Box with Loose Sides* (see Figs. 9.30–32). The method of manufacture of this type of box will vary with the number of cores required, and whether a wooden or a metal core box is called for. If a wooden core box is to be made, then the sides will be made loose, and held together on the bench by clamp or vice. If a metal core box, then metal loose pieces are made which will fit inside a metal box frame. The simple example is a core having a plain face but the sides of which carry an undercut shape. The box is rammed up, turned over on to a plate; the box is then withdrawn, leaving the loose side or sides to be drawn away from the core in a horizontal plane and at whatever angle the shape of the loose pieces may require.

The box classification, which may be called the loose-frame type, covers a tremendous variety of cores. Loose sides may be incorporated which require to contact a shape which is fixed on the base of the box. Alternatively, a shape may be fixed on the base of the box which requires to contact both the sides and the open face of the box. Any core box which is built up on this frame principle and possesses loose pieces which require to be stripped away from the box along with the core, must possess a minimum of taper of 4 deg. on the internal faces. This taper is required to ensure that the loose pieces will leave the box without undue rapping and without jamming. Owing to the fact that sand may cause these loose pieces to stick and remain in the core box, thereby destroying the core when the box is lifted away, it is often necessary to provide means of holding down the loose pieces. This is accomplished by drilling holes in the base of the box and inserting a wire, or rod, and actually holding the loose piece down on to the core plate while the core box is stripped, or taken off the core.

In a box possessing several loose pieces a frame can be made to carry rods which will hold down all the loose pieces with one operation. In constructing this type of box the patternmaker should remember that quick identification is necessary; therefore, some mark must be put on each loose piece and a corresponding mark on the frame into which it fits. It is always an essential rule that loose pieces be made so that they will fit only into their correct place in the core box. Otherwise, the coremaker is liable to try to force the loose piece into a position which closely resembles its correct position, with consequent trouble and confusion. Such methods are employed as chamfers on the corners of the loose pieces, or sets may be taken out of the back. A further point in connexion

FIG. 9.33. *Four-poster type of core box.*



with the loose pieces in the core box is that all edges should be slightly chamfered at 45 deg. This applies particularly to aluminium loose pieces. It will be found that in use the corners and edges of the loose pieces become burred, due to various reasons, but mainly through coming into contact with the bench or with the core plates. The use of a chamfered edge will prevent burring up of corners and edges and consequent sticking or jamming of the loose pieces when placed back in the box.

Another useful method which is employed is that in which contact between the loose pieces and the side of the core box is not continuous, but consists of contact strips. This eases the machining of the loose pieces and also facilitates easy withdrawal. When a wooden frame and metal inserts, or loose pieces, are employed, the contact strips on the loose pieces are made to fit against corresponding steel strips on the side of the wooden core box frame. It is essential that loose sides of a core box should dislocate themselves very easily from the main frame of the core box. If the box has to be rapped intensively in order to loosen the sides, then there is more likelihood of the core sagging and becoming distorted.

In connexion with this method, a type of core box which incorporates groups 2 and 3 of the core box classification has been developed. As an alternative to clamping together of loose pieces, or halves, of a core box, a loose plate carrying four corner pieces is used. A simplified design is that shown in Fig. 9.33, in which a core carries an opposite taper on the outer edge to that on the centre portion. The core box is made in three pieces, sides A and B, and base C, and fitted together as shown. After the core has been rammed the loose sides A and B may be lifted out from the base. The core remains between the loose pieces and may be placed on the core plate, and the loose sides withdrawn. This type of core box produces an exact reproduction of the shape of the box with the minimum of effort by rapping and turning over, and minimum wear on the core box.

(4) *Split Core Boxes.* The fourth classification of core box covers

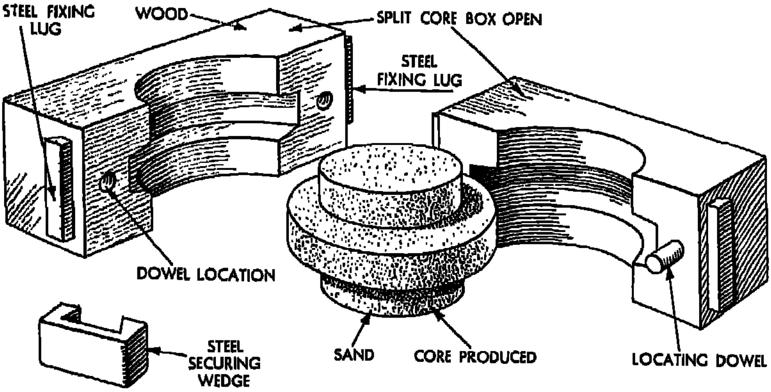


FIG. 9.34. *Split core box with open face on which to stand core.*

those cores that can only be made by the core box being split either centrally into two halves or split into three or more parts. Fig. 9.34 illustrates a simple core which can only be made by using a core box split into two halves, as shown. Portions of this type of core box may be split vertically or horizontally, or a combination of both. The separate portions of the box must be held together during the ramming operation. This can be done by means of some form of quick-acting vice fixed on the coremaker's bench, or by means of taper clips attached to the different portions of the box. The type of clip illustrated in Fig. 9.34 (inset) is most useful in holding together the different sections of a metal core box. This taper clip may be ultilized as a handle and used to obtain a steady grip of the core box during the time when each section of the core box is being drawn away from the core. With the split type of box it is essential that a suitable form of register is made, locating the different pieces of the box. The dowel pin method is mainly used to ensure this register, as shown in Fig. 9.34. Dowel pins and bushes are liable to wear and become slack and should be frequently inspected to ensure accurate location of each part of the core box.

(5) *Split Joint Core Box.* This type is used to reproduce a core which has no flat surface on which the core may be turned out. It is seen in Fig. 9.35, which shows a round branch core, the core box being made in two separate halves. Core sand is rammed in each half of the box, the two halves are placed together and located by dowel pins on one half, and corresponding holes in the opposite half-box. The open ends of the core are tucked and rammed, and the core finished inside the core box. The top half of the box is withdrawn and the core remains resting in the bottom half of the box. The turning out operation consists of supporting the core

by one of the following methods, and placing it on the plate on which it will be stoved or dried.

(1) The coremaker may, in cases where the core is small and the sand is such that the core can be handled, turn the core out of the box into his hand and place it on a prepared bed of sand. This method, however, is not satisfactory for production, and the cores are very liable to distortion.

(2) This is the correct method for removing a core which cannot be turned out on a flat plate (see Figs. 9.36–39). The one half of the core box is withdrawn, leaving the green core sitting in the other half of the core box. A sand bed must be formed round about this core to support the core plate, which is placed on the sand, and before the whole is turned over. To ensure that this sand bed is suitably formed and held together during the turning-over operation, a frame is made. This frame, a bedding frame, as it is termed, is made to locate on the half of the box in which the core is left. Bedding sand, which is unmilled moulding sand, well riddled, is lightly placed over the core, fingered and made to form a firm support around the core. The sand is then made level with the top of the frame. The half-core box containing the core, the bedding frame and sand, should now be turned over and the core left sitting on the bedding sand. To obtain this result the core plate is placed on top of the frame, the operator places one hand on the top side of the core plate and the other on the underside of the core box and turns the frame and half-core box completely over. This means that the core is left resting on the bedding sand with the half-core box resting on the bedding frame. The core box

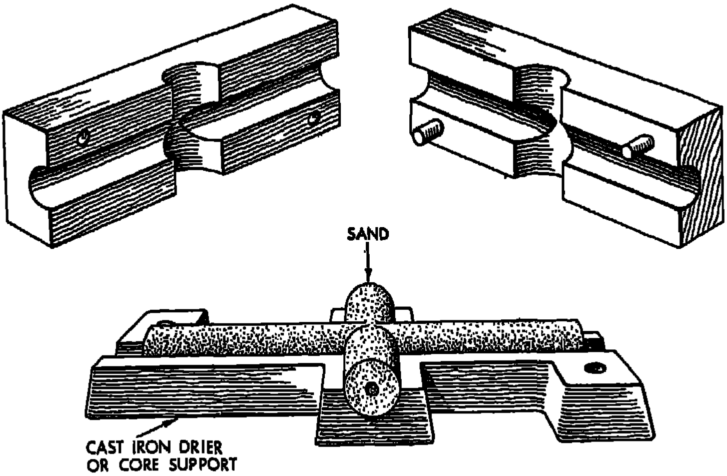
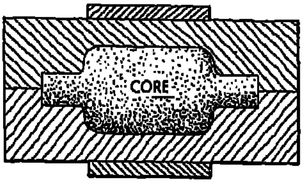


FIG. 9.35. *Core box in which support must be given to the core on being turned out.*



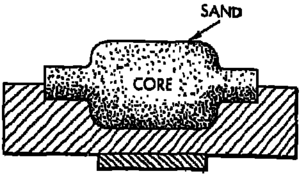
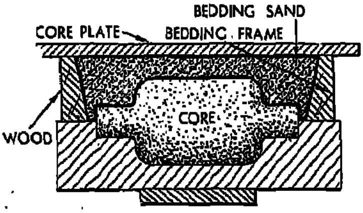


FIG. 9.36. *Section showing finished core and core box.* (Right) FIG. 9.37. *Core remaining in the core-box bottom half.*



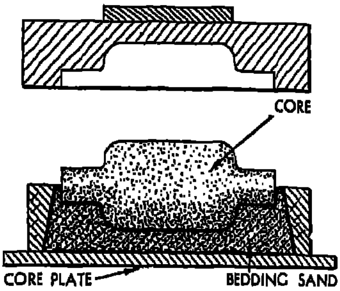


FIG. 9.38. *Frame, bedding sand and core plate in position before rolling over.* (Right) FIG. 9.39. *Half-box withdrawn and the bedding frame ready to be drawn.*

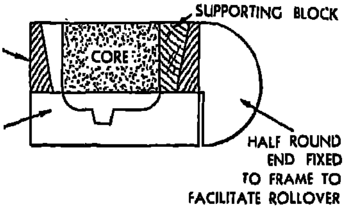


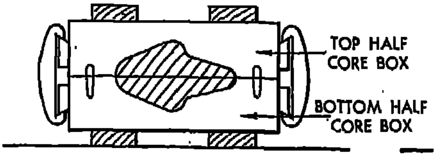
FIG. 9.40. *Method of utilizing bedding frame to facilitate roll-over.*

is now withdrawn and the bedding frame removed. Bedding frames may be made to suit all sizes of cores and may be fitted with side pieces which help the rolling over of the core. A bedding frame may be used to turn over a core and act as a support during the roll-over operation, even if no bedding sand is needed. A frame used in this fashion is shown in Fig. 9.40.

(3) With this classification of core box, if large quantities of cores are required, a different method of turning out the core should be employed. This is accomplished by means of metal shapes which fit the half-core and are called core driers or formers.

CORE DRIERS

Core driers are known in the foundry trade by many different names; they may be called driers, formers, supports, shells, or carriers. Here, for



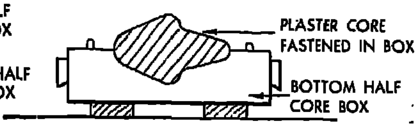
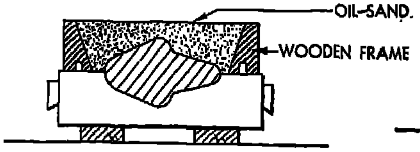


FIG. 9.41. *First operation in manufacture of a core-sand drier.* (Right) FIG. 9.42 *Second operation.*



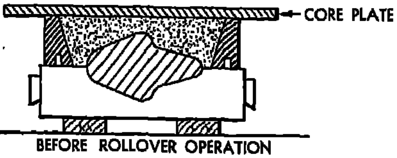
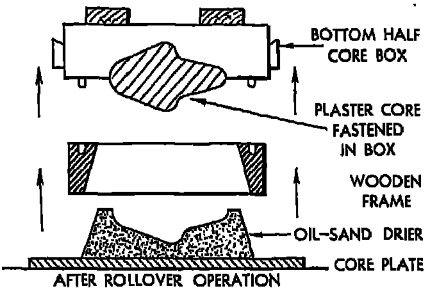


FIG. 9.43. *Third operation.* (Right) FIG. 9.44. *Fourth operation.* (Below) FIG. 9.45. *Final operation.*



the purpose of clarity, they will be referred to as core driers. A core drier consists of a part-reproduction of the shape of the bottom half of the core. Core driers must fit the shape of the core and must be located accurately in position around the core. This location is effected by using dowels in the core box and dowel holes in the drier. Driers give best service when made in cast iron. Malleable iron and aluminium may be used, but a suitably designed cast-iron drier, ribbed to give strength, is to be preferred. The drier must be so designed that it does not warp or twist in the heat of the stoving operation.

Core driers may be made in a hard drying oil-sand. Oil-sand is used for driers when the quantity of cores called for does not justify metal driers being made. Oil-sand driers are made as shown in Figs. 9.41-45. A plaster core is made and placed in the core box, bedding out frames made and fitted, oil-sand is rammed to occupy the space between the plaster core and the bedding frame. Metal locating dowels may be rammed in position. The drier is turned on to a core plate and painted or sprayed with linseed oil. Some means of preventing the drier sticking to the core plate due to the excess linseed oil employed, must be used. A double layer of paper, or a dusting of parting powder, will prevent this sticking. The drier, after baking, is fitted by rubbing on to the plaster core and location dowels. A suitably made oil-sand drier may be used for many weeks if care is taken, and after a certain time a further coat of linseed oil is given. Such materials as cement of heat-resisting nature may be used for driers for cores. Location of driers is of extreme importance—a faulty location of the drier causing cross joints on the core.

Having been given a suitable box, the coremaker's skill is exercised in various ways. Firstly, it is needed to determine the exact wire required to support the core, when green, and reinforce the core, when dry; secondly, in the placing of the wires in such a way that they will not spring and distort the core after the box has been withdrawn; thirdly, in the completion of a firmly and evenly rammed core capable of being withdrawn from the core box; fourthly, in the placing of vents so that gases created, during casting, may be led away through the most suitable core prints; and, lastly, to manipulate the core box and loose pieces so that a core is withdrawn which is an exact replica of the inside of the box.

CORE VENTS

The venting of cores is an operation to which utmost consideration must be given. When a core is completely surrounded by metal large volumes of gas are generated, and vents must be made in the core to form passages whereby this gas may find quick release from the core. If there is no quick release for the gases generated, then they are likely to try to obtain outlet through the metal with consequent blown castings. A core vent is a hollow passage formed in a core leading from that part of the core which is surrounded by metal to such a place in the core from which gases may be led off to the atmosphere. This usually means that the vent is connected to the core print at the joint of the mould. Vents may be formed in cores by:

(1) *Wax String Vent or Strum.* This consists of a special waxed string, which is bedded into the core during ramming up. During the stoving operation the wax melts and leaves a hole forming a clear passage for exit of gases. Wax vent is especially useful when intricate shapes have to be vented. The wax vent can be twisted and shaped into thin contours and passages of the core. The wax is built up on several strands of cotton, which, after the wax has melted, should be withdrawn from the core.

(2) *Pierced Vents.* The most simple method of venting is to pierce the core with a vent wire while the core is still in the core box. The vent wire is inserted through the open core print and then withdrawn, leaving a clear passage for gases to be led away through the print and from the mould.

(3) *Coke or Ashes as a Venting Medium.* All large cores require to be vented extensively. To do this the coremaker utilizes a bed of coke, or

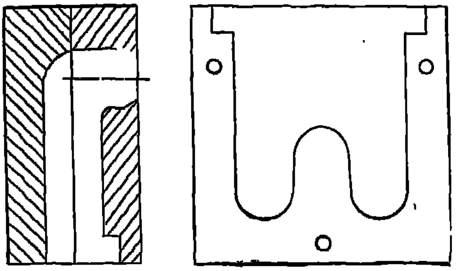
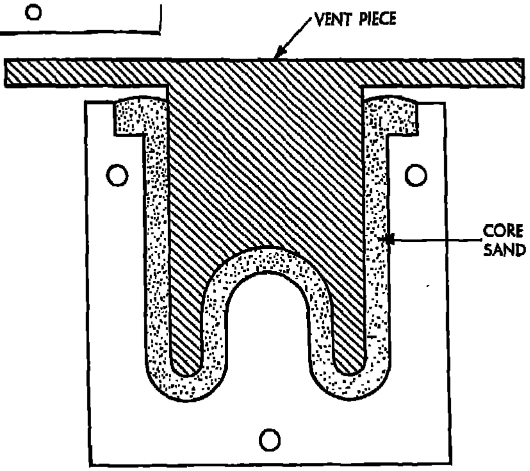


FIG. 9.46. *Type of core box to produce a hollow core.*

(Below) FIG. 9.47. *Steel vent piece forced into core-sand.*



ashes, in the centre of the core which lead to a main print or prints. During ramming up, the core sand is faced around the core box to a depth to suit the size of core, and then the centre of the core is filled up with ashes or coke. On the open face of the box a further layer of core sand covers the coke. During casting, the gases find a quick entry into the coke bed, which allows their free passage to the provided outlet in the print or prints.

(4) *Gallery Vents.* Vents may be formed by placing a wire in the core during the ramming operation and withdrawing the wire through the core box after the core is complete, but before the stripping operation is carried out. A series of vents may be made in a core by the insertion of steel wires through holes drilled in the core box.

(5) *Venting by use of Hollow Core.* A very useful production method of venting cores is shown in Figs. 9.46–51. This method is used where it is required to vent a small or medium size core, and to lead the vent away to one point. Sand is rammed lightly into the core box, and then the vent piece is forced into the sand. The vent piece is so formed that it leaves ½ in. to ¾ in. of sand around the walls of the core. The vent piece is then withdrawn and into the space it leaves is poured dry silica sand. The silica sand is filled to within ½ in. to 1 in. of the top of the core box, and the core is then completed with core sand. After the core has been baked, a hole is pierced at any required place in the print, and the dry

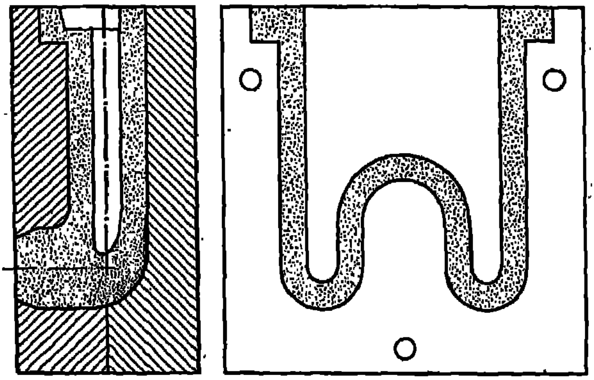
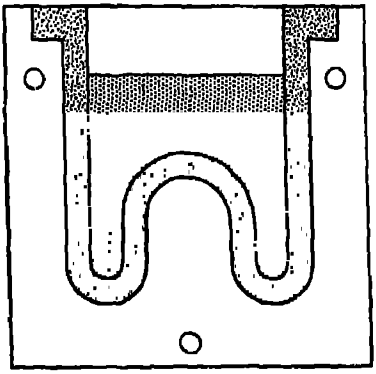
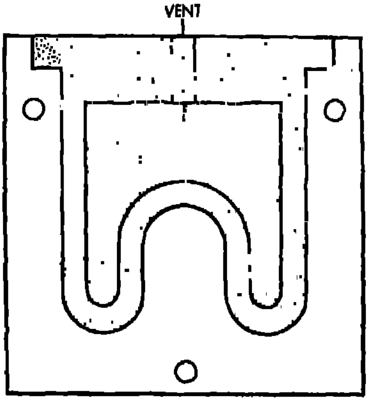
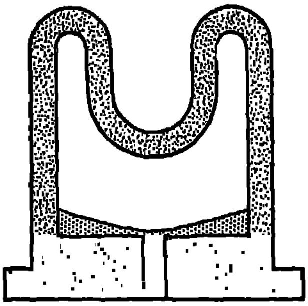


Fig. 9.48. *Sectiona views of the core after the vent piece has been withdrawn.*





(Above, left) Fig. 9.49. *Dry silica sand filled into the recess.* (Above, right) Fig. 9.50. *Oil-sand core completed.* Fig. 9.51. *Dry core inverted, allowing silica sand to run out from the centre of the core.*



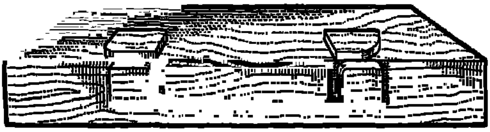
silica sand is allowed to run out of the core. When this is done the core is left with a hollow centre. This method of venting works extremely well in such types of core as shown in Figs. 9.46–51. The operation of forcing in the vent plate ensures that the core is well rammed, and also a maximum of venting from the inside of the core.

CORE GRIDS OR CORE IRONS

Core grids are the means whereby large and medium cores are reinforced and strengthened. It will be readily seen that cores made from a comparatively weak sand require extensive support when their weight reaches up to several tons. In each production foundry will be found a grid bed, or a section where the core grids, or core irons, are made. This grid bed is formed by laying two rails along the sides of a pit up to 5 ft. deep. A 12-in. layer of ashes is placed in the bottom of the pit, and then filled up with riddled sand to floor-level. The sand is then strickled off by means of a board laid across the two rails. On this bed of sand is laid either the actual core box for which a grid is to be made, or a template giving the shape of the required grid. An imprint of the shape is made, or by shaking on parting powder or silica sand before removing the template, an outline is left on the face of the sand. The coremaker then sets to work with dabbers, or pieces of wood shaped into the section which is required in the grid. This dabber is forced into the soft sand bed, and the outline of the grid made. A core grid consists of, not only a flat grid, but also prongs which will support the weight of the core. To make these prongs, a pointed bar is pushed into the sand in convenient places in the grid outline to the required depth. Steel lifters, or handles, are inserted into the open sand mould thus formed. The open grid mould is then poured and the coremaker obtains the grid to suit his core. It is the general practice to make grids in cast iron and to break them to get them out of the casting. In large cores several grids may be used. When this is done it is essential that they be bolted together securely.

CORE WIRES AND CORE PLATES

Core wires are used for reinforcing purposes in a similar manner to core grids and core irons. For the repetition production of intricate cores they should be made in large quantities, and as they must all be of exactly the same shape they should be formed in a wire jig. The jig consists of a hardwood block into which steel pins are driven to form the required



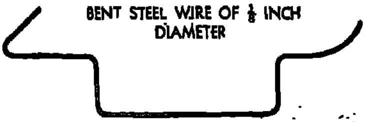
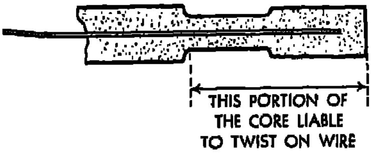

BENT STEEL WIRE OF ⅛ INCH DIAMETER

FIG. 9.52. *A wire-bending jig.* (Right)
FIG. 9.53. *Shape produced by this jig.*



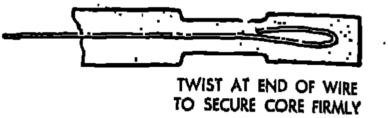


FIG. 9.54. *Incorrect insertion of core wire.* (Right) FIG. 9.55. *The correct method.*

shape. To facilitate the bending of the wire and to prevent the wire hardening after heat treatment, it is best to employ a core wire made of soft malleable iron. The jig method of bending the wire enables it to be formed in one, two, or three planes—a typical example of such a jig being shown in Figs. 9.52 and 9.53. Figs. 9.54 and 9.55 illustrate respectively the incorrect and correct ways of inserting a core wire. An important point to remember is that round wire allows the core to twist about the wire. This, however, can be overcome by giving the wire a coating of gum, or linseed oil, before insertion. Further, in some foundries it is the practice to use a square core wire as an extra precaution against twist.

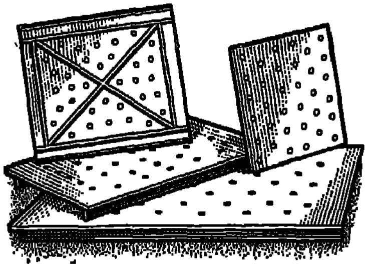
The requirements of a core plate are that it should be perfectly flat and rigid, it must not distort with handling, or with the heat of the core stove, and it should be such that it will sit firmly when placed on any type of bench, conveyor or rack. Fig. 9.56 illustrates the type of core plate which fulfils all normal conditions for general use. Core plates can be made in either cast iron or aluminium. Larger sizes of core plates may be of welded steel construction. Core plates which have to be used on a roller track must possess strips on the underside. These will guide them over the rollers and will not, in any circumstances, allow jolting of the core while the plate passes.

MECHANICAL PRODUCTION OF CORES

IT is first necessary to state the operations required to produce a core. These are:

(1) Place sand in core box and ram firmly and evenly,
(2) Finish off core flush with top open edge of box,
(3) Place core plate in position on top of core,
(4) Turn over core box and plate,
(5) Vibrate,
(6) Withdraw core box, leaving core sitting on core plate,
(7) Pass core to stove.

Machines have been introduced into the core shop which assist in the production of cores, but the application of any mechanized means is governed entirely by the design of the core. The first operation in the



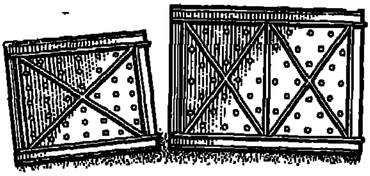


FIG. 9.56. *Typical core plates that fulfil all normal requirements.*

making of a core, i.e., the ramming of the core sand, can be accomplished by four methods:

(1) Hand-ramming of the sand into the core box,
(2) Blowing of sand into core box,
(3) Jolting of the sand in the core box,
(4) Vibrating and compression by squeezing sand into core box.

Coremaking machines have been developed using each of the above methods of sand ramming. As a mechanical means of core production, the core blower is most widely used, but it can only be used with success when making certain types of cores. The application and methods of core blowing are described later in this chapter.

JOLTING METHOD

The jolting of a core is a production method which is most successful on large- and medium-sized block cores of a simple design—it calls for similar technique to that of jolting a mould. Undercut flanges, or loose pieces, should be avoided as far as possible. Moulding machines can be used very satisfactorily for the production of cores as they provide an ideal method of production for large- and medium-sized block types of core. The core box is fastened securely on the machine table, sand placed in the box and the table jolted.

The core can be made by utilizing both the jolt and squeeze action of the machine. The squeeze is made effective by placing a frame over the box and filling it with sand up to the top of the frame. The sand is then jolted and again levelled off to the top of the frame. Next, the frame is removed and the core box squeezed against the head of the machine. Finally, the squeeze is taken off and the core finished by strickling off the sand level with the open face of the box.

It is then necessary to place a core plate over the open face of the box and again set the machine in the squeeze position. The machine is then rolled over and vibrated. The stripping operation now takes place, the core box is slowly withdrawn, thus leaving the core sitting on the core plate. When the stripping operation is complete, the core plate and core

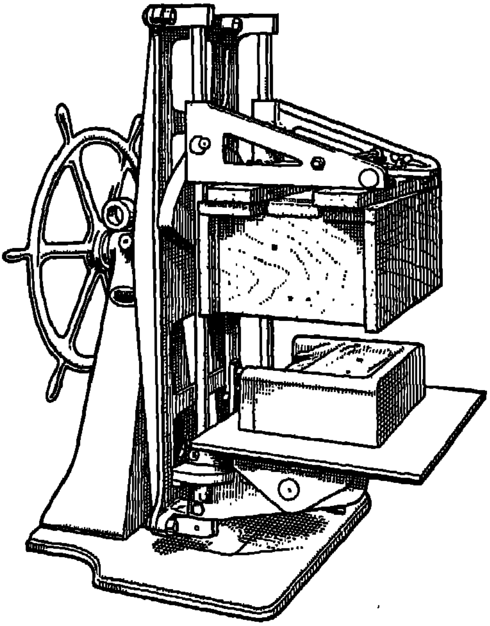


FIG. 9.57. *Roll-over type of coremaking machine.*

are withdrawn and the machine rolled over to its original working position. Fig. 10.30 shows a roll-over type of jolt squeeze machine well suited to the production of cores; Figs. 10.34 and 10. 35 illustrate large roll-over, power-operated jolt and pattern strip machines which are very useful for dealing with large size cores, particularly in production quantities. The operation of these machines is detailed in Chapter 10. Fig. 9.57 illustrates a hand roll-over and draw machine for making small- and medium-sized cores.

A vibrating table is very often used for the manufacture of multiple cores. The fact of vibrating the core box ensures efficient packing and flowing of the sand into the corners of a core box. Many core shops employ a small jolting table fitted into the coremaker's bench so as to facilitate ramming of cores. This method requires that the core box and core plate be rolled over by hand.

A type of core machine used entirely satisfactorily for the production of all round cores from ⅛-in. diameter up to 6-in. diameter is shown in Fig. 9.58. This machine may be hand or motor driven. The sand is fed into the hopper and forced by means of a worm through a fixed size of die. The core is extruded and is guided along slots in a carrier plate. In the larger sized cores the machine necessitates individual shaped formers, or carriers, for the core. For large cores a sand slinger may be employed to replace the operation of hand ramming.

Small air-driven sand rammers are also used for peg ramming, or flat ramming of large cores in either black sand or oil-sand.

CORE-BLOWING MACHINES

A core-blowing machine produces cores by the action of forcing the sand by air pressure into the core box. The sand is introduced into the box through an outlet nozzle from the pressure chamber in the core blower. The core box is held by means of clamping devices during the blowing operation.

There are two types of core-blowing machines manufactured: they are the vertical and the horizontal type. Fig. 9.59 shows a vertical-type machine, and Fig. 9.60 shows a horizontal-type machine.

The first machine in this country was delivered to a foundry making sewing-machine castings, and after about a month of intensive experiments some good results were obtained. Later, some glass core boxes were made, so that it could be seen what happened when the sand entered the core

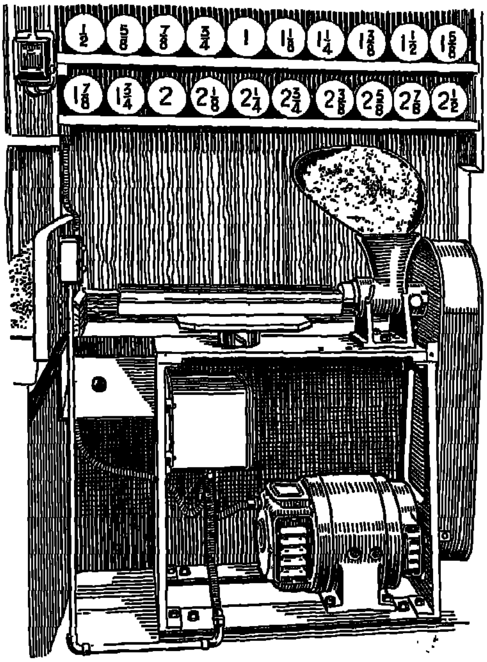
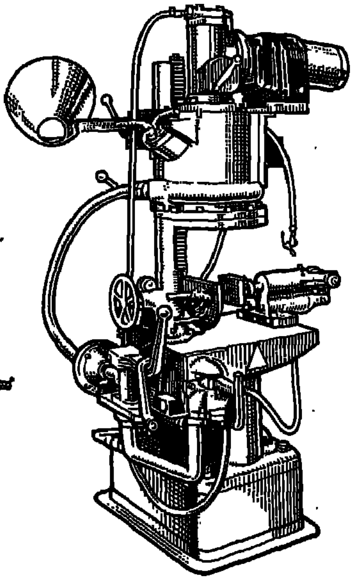
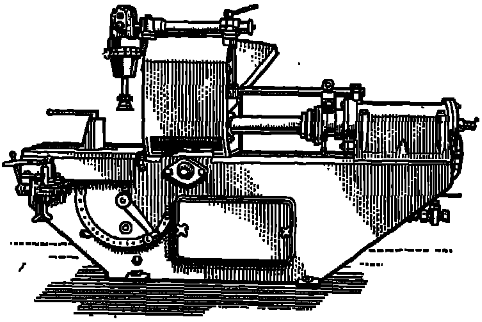


FIG. 9.58. *Motor-driven core-extrusion machine for cores of ⅛ to 6 in. diameter.*





(Right) FIG. 9.59. *Electrically-driven vertical type of core-blowing machine.* (Below) FIG. 9.60. *Horizontal core-blowing machine.*

box, and from this experiment much useful data was obtained. Various types of sand were used, such as black sand and oil-bonded sand, etc. It was found that whilst black sand could be used for blowing fairly simple cores, oil-bonded sand was most suitable for blowing the more intricate cores.

At first, core-blowing machines were mainly used in iron foundries making such cores as manifolds, valves, pistons, mincing machines, etc. Later, they were installed in brass foundries making household taps, bib-cocks, and petrol delivery nozzles, etc. Then the malleable foundries became very busy, and core-blowing machines became necessary in order to cope with the bottlenecks which were taking place in the core shops. The machines were used for such cores as cycle hubs, trench mortar bombs, conduit fittings, and pylon fittings, etc. Aluminium foundries gradually started to install the machines, and now practically all the leading aluminium foundries are using the machines with success. Up to only a few years ago, core-blowing machines were not very popular in steel foundries, the chief reason for this being the rather heavy core sand which was used; now, however, in these foundries making smaller types of castings such as track links, etc., the machines are constantly being used to their maximum capacity day and night.

As regards the technique of core blowing, it is rather difficult to explain the various ways of overcoming the snags and difficulties, as each individual core has its own peculiarity. The following hints and suggestions may be useful:

(1) Core boxes should be checked periodically to see that joints are in good condition and that, if possible, the end at which the box is blown is at exact right angles to the bottom of the box.

(2) Always have plenty of sand in the machine, otherwise air is mixed with the sand whilst blowing, and the boxes will quickly become worn.

(3) Owing to even ramming and the greater permeability of the core, venting is not always necessary.

(4) Although a blown core in its green state is softer than a hand-rammed one, it will be found that after baking the core will be at least twice as strong.

(5) When a worm hole appears in a core it is often due to the fact that the core box is not a good fit at the joint, or that the box is not square on the machine, and thus sand is leaking from the box.

(6) Where soft spots appear on a core it can usually be attributed to one of two things. In the first place it may be due to air being trapped in the box, and this frequently happens in a deep pocket, or recess, of the box. This air must be displaced so that the sand can take its place. This

is done by drilling a hole at the affected place and inserting a vent, which is specially made for this purpose. These vents have holes, or slots, in them sufficient to let the air escape, but not the sand. Secondly, it may be due to the sand by-passing at the place where the core is soft; to overcome this it is advisable to alter the direction of the shot, if possible, so that the sand is blown direct against the affected spot, or by slightly chamfering off any sharp corners. This trouble may occur if the sand is rather on the heavy side.

(7) On some cores where a thin section leads to a thicker section they may tend to be weak at this point and break, or are inclined to be soft. If possible, carry out the suggestions outlined above, that is, chamfering off any sharp corners or using a slightly less bonded sand.

(8) When possible, the blowing nozzle of the machine should be as small in diameter as the smallest diameter of the core box, when this diameter is in direct line of shot. Unless this is done the box may tend to be blocked before the core is fully blown.

(9) When blowing a long core use a small diameter nozzle, and on block cores use as big a nozzle as possible.

(10) In many cases wires can be dispensed with, but this depends entirely upon each particular core in regard to casting conditions, etc. If wires, however, are found to be necessary they can be either placed in the core after blowing or by fixing small pegs in the box to hold the wire in position whilst blowing. If possible, these pegs should be fitted in the print of the box.

CORE STOVES

The baking, or drying, of a core is an operation which demands careful attention, as a core incorrectly dried can be the cause of a scrap casting. Core stoves must be so designed that they will allow oxidization of the oil in the core-sand and complete evaporation of all moisture in the core. The core must be maintained at an even temperature of 500 to 520 deg. F. for a period of from 2 to 8 hrs., depending on the size of the core and the nature of the sand. Hot gases must be allowed to circulate round the core to supply oxygen, which will cause the oil in the sand to become a thin, hard film, and so create the dry strength of the core. The circulation of the gases also causes the steam from the moisture content of the core-sand to be withdrawn through the vents provided in the core or through the spaces between the sand grains. A core stove may then be termed a chamber in which hot air and gases are circulated and maintained at a temperature of 500 to 520 deg. F. The core stove must be so designed and built that cores can, without undue shaking or movement, be placed into and withdrawn from the heating compartment with the minimum amount of labour. The type of stove to be used in any particular foundry depends on the class of core and the quantity of cores made. Various types have been designed for this purpose.

DRAWER-TYPE STOVES

For a core shop engaged on medium quantities of small cores, a coke- or gas-fired drawer-type of stove can be installed. This stove consists of a heated chamber into which are fixed a series of shelves, or trays. A drawer-type stove is so designed that one drawer, or tray, can be withdrawn, cores loaded or unloaded, and the drawer replaced without undue loss of heat. Fig. 9.61 shows one example. The heating of the drawer, or fixed tray-type core stove can be from a coke-fired unit from which hot air is circulated evenly, and a constant temperature maintained. This type of stove is made with gas burners as an alternative method of heating.

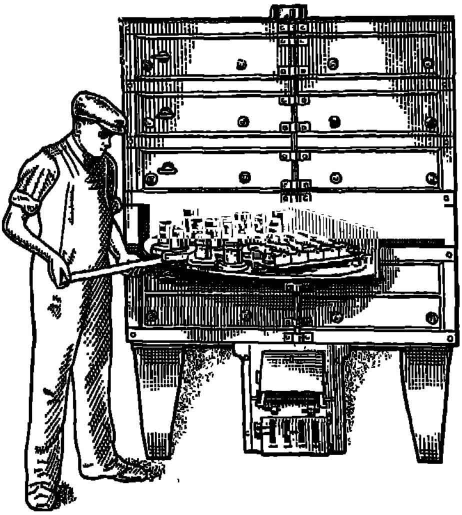
For larger quantities of cores of possibly greater varieties in size, a fixed-shelf type of core oven may be used. This consists of a heating chamber in which is fixed a series of shelves. Doors of a hinged or sliding type form the front of the stove. The correct way to operate this type of stove is to fill it completely with cores to be dried, the heating dampers, or gas jets, then being turned on and the doors shut. The stoves should be left for a specified time according to the size and nature of the cores to be baked. At the end of this time the heat should be turned off, the doors opened, and all the cores withdrawn. This type of fixed-shelf stove is very often used in such a way that the heat is wasted due to the doors being continually opened either to put in or take out one or two cores.

BATCH-TYPE STOVES

For consistent drying of large quantities of varying sorts and sizes of cores, a series of batch-type core ovens should be installed. The batch-type core oven is a permanent brick-built oven so designed that a rack of cores to be dried may be placed into the oven, the doors closed and then, after a predetermined time, the rack can be withdrawn and replaced by another rack of cores brought on a bogie. The batch-type stove is usually heated by means of a coke fire box, with suitable fan and damper arrangements to enable each of the stoves in the series to be maintained at any required temperature. The flues for this type of stove are usually built into the base of the stove. Each stove has a hot-air inlet at the back of the heating chamber and two exhaust outlets to a suitable chimney at the front of the floor of the chamber. The doors of these stoves are of a balance-weight type, which lift vertically. They are, however, securely held in their working position by means of cam-type retaining clamps.

A core-shop working with a series of two-, four-, or six-batch-type

FIG. 9.61. *Operation of a drawer-type core stove. Each drawer can be opened for loading or unloading when required.*



stoves can so arrange the baking of the cores that each stove deals with a certain type and size of core. One rack may be loaded up with large black sand cores, which require 4 to 6 hrs. drying. This rack can then be placed in one compartment of the stove and left for the specified time. The next portion of the stove racks, however, may be loaded with only light cores, which only require 1½ hrs. drying. Without interfering with No. 1 compartment, No. 2 compartment can be opened, the cores withdrawn and the second rack of cores placed in for drying. The batch-type of stove with a suitable means of conveying loaded core racks to and from the stove provides the most flexible means of core drying. The main advantage is that large variations in type, sort and size, and of drying times, can be obtained easily.

CONTINUOUS-TYPE STOVES

For the foundry engaged on mass production of cores of uniform size and type, a continuous type of drying stove should be installed. The continuous type of stove consists of a vertical steel chamber; into this are fixed, by means of steel shafts and sprockets at the top and base of the stove, two steel chains. Between these chains are slung a series of steel carriers. The operation is such that at the base of the stove the carrier is loaded with cores. The rack, or carrier, is then slowly lifted into the heating zone of the core stove, and is allowed to pass through this heat for a period of time which can be regulated. This time varies between 1 and 3 hrs. The carrier then travels round the stove and returns to its original position. Cores can then be unloaded and further cores placed on to the carrier for drying. Fig. 9.62 illustrates this method. The heating of the continuous type of stove is by a fire box from which hot air is blown into the heating oven above the loading portion of the stove. The

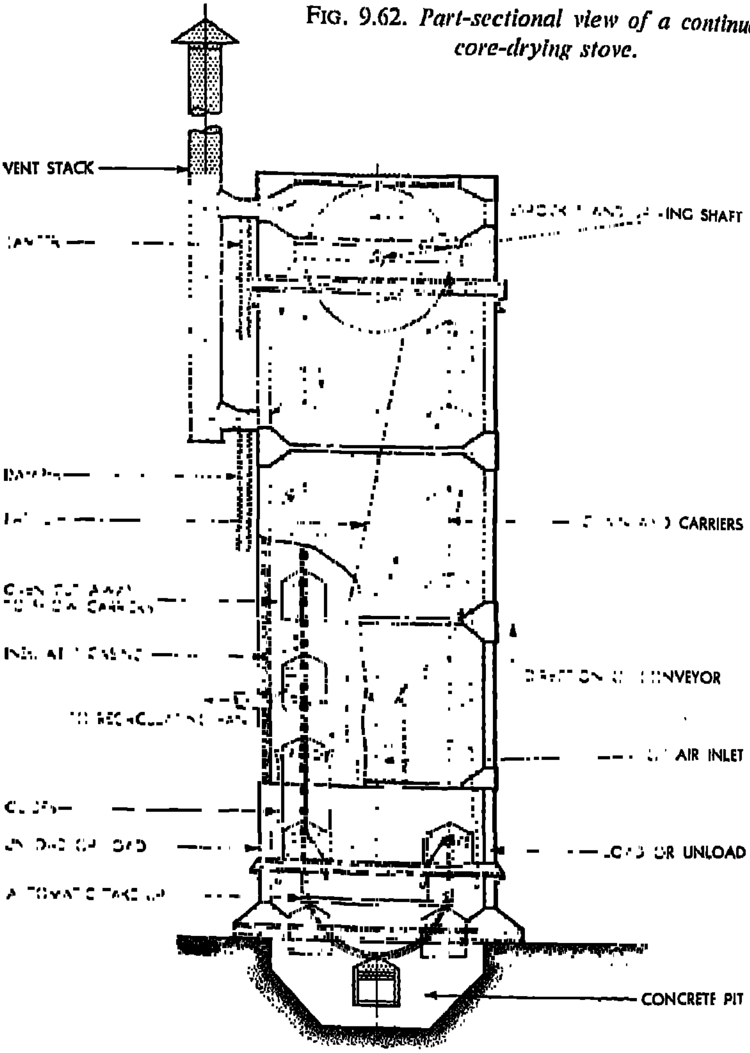


FIG. 9.62. *Part-sectional view of a continuous core-drying stove.*

vertical type of continuous stove assures a continuity of core-shop operations and provides maximum core drying in a minimum of floor space.

The vertical-type continuous stove is made in sizes to suit varying capacities of core shops, while the single-chamber type of core stove is made with varying numbers of chambers. It is, however, the general practice to run a four-chamber stove and, on this larger type of stove, devices are fitted which cause automatic loading and unloading of the cores. To work the automatic loading and unloading of a four-chamber continuous-type stove the cores must be of a fairly consistent size and weight, and must be mounted on core plates which fit within the sizes of the shelves. In front of the stove, roller brackets are fitted, the cores are placed on the rollers and pushed forward on to a series of skids; the shelves consist of a series of angles which travel up through the skids. The cores are then lifted off the skids and carried through into the heating zone. At the unloading end of the stove more skids are in place, and the shelves are lowered through the skids. Core plates and cores are retained on the skids, and are then withdrawn by hand on to the roller brackets. It is usual to place the cores on some form of conveyor or storage rack.

CONTINUOUS STOVES

In certain core shops, mechanization has been such that core drying is done through continuous stoves which are built horizontally and through which a pendulum conveyor passes. The cores, after being made, are placed on a series of pendulums. These pendulums pass through a horizontal chamber which is heated to a specified temperature. The speed of the conveyor in conjunction with the length of the core stove is such that cores are allowed the correct baking time. For large cores, bogie-type core stoves are essential. These stoves consist of a heating chamber, governed to temperatures of 500 to 520 deg. F., giving suitable quantities of circulating air. Large cores are loaded on different types of bogies made to suit the conditions of the particular stove.

The fact that the bogie has to remain in the stove during the stoving operation means that care must be given to the axle arrangements of the bogie. The bogie must be of the free-running type, which will not cause seizing-up of the bearings. Any lubricant used must be capable of resisting the high temperatures which occur in the stove. A bogie which has been developed to overcome this difficulty of transportation into and out of the stove is constructed with two V-shaped bearers along the underside. Similar V-shaped bearers are built into the floor; into these bearers are placed a series of cast-iron balls which act as rollers and allow smooth propulsion of the core bogie into the heating zone. There is nothing to corrode or seize up due to the heat, and the bogie works smoothly and without undue shaking.

JOINTING OF CORE-SAND CORES

Various types of cores may be made in separate halves which are capable of being turned out on to a flat plate. To ensure correct jointing it is advisable to put a jigging operation on each half of the core before they are jointed. A core may, if made in one piece, sag during the drying and be under size on inspection. To prevent this the core is made in two halves and $\frac{1}{16}$ in. to $\frac{1}{8}$ in. excess sand left on the joint face. The core is then placed in a rubbing and checking jig and the excess sand on the face is removed to a set level. The two halves of the core are treated in this fashion, and thus an exact core is produced. Various methods of jointing cores are employed, as follows:

(1) *Core Compound.* This method is achieved by using a diluted core compound, or core gum. The compound should be mixed with hot water to form a slurry and then boiled.

(2) *Flour Paste.* This is used for jointing non-ferrous metal cores, and in cases where metal is in contact with the joints of a core in order to prevent blowing from a joint.

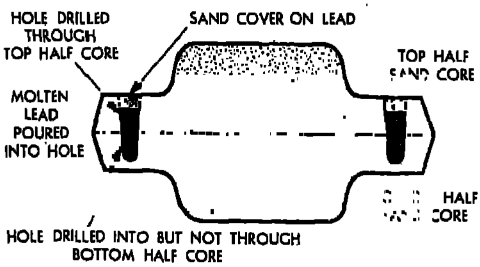
(3) *Dowelling Method.* In certain cases cores may be dowelled together by:

(*a*) Use of molten lead, (*b*) Plaster of Paris, (*c*) Quick-setting cement, (*d*) Tapered insert methods, (*e*) Plastic insert methods.

Fig. 9.63 shows the method of dowelling two half-cores. Molten lead is poured into the cavity, immediately sets and forms a perfect jointing dowel, which cannot be removed, except by breakage of the core. This practice is used chiefly on cores in the cast-iron foundry. The use of lead in the non-ferrous foundry is likely to lead to complications, due to the lead, after casting, becoming mixed with the scrap metal and causing trouble on remelting.

In a non-ferrous foundry, plaster of Paris or a special quick-setting cement may be used without any of the detrimental effects for this type of dowelling operation.

Fig. 9.64 illustrates a method of jointing two halves of a mass-produced core with the minimum amount of trouble or labour. In each half of the core box a taper block is fixed. The two half-cores are jigged and a sand or metal insert placed in position. The insert may be recovered and reused. The jointing of a particular core may consist of a groove


HOLE DRILLED THROUGH TOP HALF CORE
SAND COVER ON LEAD
TOP HALF SAND CORE
MOLTEN LEAD POURED INTO HOLE
HALF CORE
HOLE DRILLED INTO BUT NOT THROUGH BOTTOM HALF CORE

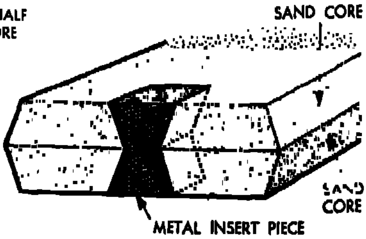


FIG. 9.63. *Method of jointing cores by the use of molten lead—known as the dowelling method.* (Right) FIG. 9.64. *Method of jointing two half-cores by wedge piece.*

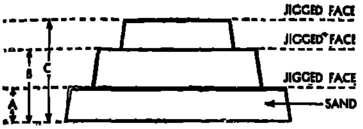
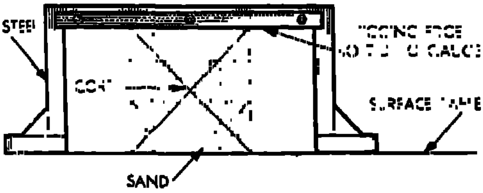


FIG. 9.65. *Diagrammatic arrangement showing jigging of faces of cores.* (Below) FIG. 9.66. *Jigging cores by the use of a bridge gauge.*



being filed, or the core box so fixed that a groove is produced. A wire is then placed in this groove and cemented into position by means of a quick-drying cement. An alternative to cement is a compound made of flour paste and oil-sand. It will be found in practice that equal parts of flour paste and oil-sand mixed together into a fairly plastic cement will, on slight heating by a gas flame, harden and produce a jointing material which is equal in strength to dry oil-sand. This jointing material can be usefully employed in the core shop in the patching of cores. The jointing paste possesses the unique advantage of quick drying by means of a gas flame, or limited stoving.

TREATMENT OF CORES AFTER STOVING

Cores are liable to sag and distort during the baking or drying process. Chief reasons for this are variations in sand mixtures, ineffective ramming operation and bad handling before being dried. Therefore, as the moulder insists on cores being correct in every detail, each core must be examined and, if necessary, dressed. It is important to note that a slight sag, or bulge, in a core will result in an imperfect casting, i.e., the casting will be thick or thin in a certain section. Should this happen it will either mean considerable expense in repairing the casting or in all probability scrapping it altogether. The importance of thoroughly inspecting and dressing a core cannot, therefore, be too strongly stressed. Visual examination is not always sufficient to pick out a slight sag, or bulge, and other means are usually resorted to. Perhaps the most universal of these is checking with the aid of a jig. It should be made to fit that part of the core which is liable to sag or distort.

When a series of two or more cores are assembled and rest on each other in the stove they can be jigged to size. On the contact faces of the cores an excess thickness is allowed so that after they are baked a rubbing jig is placed over them, and the excess sand scraped off with a straight-edge. Fig. 9.65 shows a series of three cores typical of those very often in daily use. The cores shown are assembled the opposite way to which they fit in the mould. Each height, A, B and C, is checked by means of a bridge gauge. This bridge gauge must be so constructed that easy correction for wear can be made. Most bridge gauges, therefore, have an adjustable top piece for this purpose. In order to maintain these rubbing jigs a useful means employed in the production core shop is to use a scrap saw blade for the action part of the jig which is in contact with the sand (see Fig. 9.66).

Another method of checking the cores is to utilize a permanent mould, and to fit each set of cores into the mould. Metal thickness and contours can then be checked and cores corrected if any variations have taken place. Plaster of Paris moulds, with steel strips inserted at points liable to wear due to constant insertions of cores, provide an excellent method of checking production cores. As well as checking the size and shape of cores, the venting arrangements should also be checked. A simple production method of checking the vent in a core is to connect a gas supply to one end of the vent and plug the opposite end by means of clay or paste. By following the contours of the core with a flame any leaks of gas from the vents are detected immediately, and can be covered and made correct.

After a core has been jigged and inspected it may be painted. The painting of cores, particularly oil-sand cores, should be done only after the first inspection and jigging operations have been completed. A core may be painted to produce a good finish on the casting and to ensure that the core sand strips clean from the face of the casting. Various coatings are used in the core shop for the painting of cores for use with different metals. The coatings used consist of varying proportions of plumbago, graphite, talc and silica flour, together with some form of binder such as sodium silicate. There are many coatings sold under trade names, each of which has its advantages when used with a particular metal. A simple mixture of two parts of plumbago and one part of talc, or french chalk, with approximately 5 per cent dextrin, the whole mixed into a wash of suitable consistency, will give satisfactory results in the majority of foundries. The coating may be applied to a core by spray, by brush, or by a dipping process. Cores thus treated must be dried after the coating has been applied.

CORE-SHOP MECHANIZATION

MECHANICAL aid can be used in the core shop for the following operations:

(1) Unloading of sand from transport vehicles into storage hoppers,

(2) Drying of moist silica sand and the conveyance of dried sand to the storage hoppers above the mixers,

(3) Sand mixers,

(4) Delivery of mixed core sand to coremakers,

(5) Delivery of finished cores from coremaker to drying stoves,

(6) Handling of cores from the drying stoves to finishing and inspection section,

(7) Return of core plates to coremakers.

Sand for the mixing of oil-sand must be dried before use, and, therefore, any mechanization in the core shop must cover sand-drying equipment. There are various types of sand driers:

(1) Rotary kiln or revolving-drum type drier,

(2) Vertical cone-shaped drier,

(3) Horizontal stationary-type drier.

It is general practice that core sand should be unloaded from the transport wagons and delivered into storage hoppers. An inclined belt conveyor, or a bucket elevator, is used for this operation. The silica sand storage hoppers are usually placed adjacent to the sand-drying equipment. The moist sand is withdrawn from the base of the storage hoppers by means of a circular revolving table on which a scraper arm is fitted. The sand is scraped off this revolving table into the sand drier. The rotary sand drier consists of a heated drum through which the sand is passed. The drum is set at an angle and made to revolve. The sand is fed in at the higher end of the drum and, due to a series of flanges, is given a turbulent action as the drum revolves. The drum is heated either by a direct gas or oil flame, or by means of hot air drawn from a coke firebox.

Whichever form of drier is used, the sand is heated during the process and must be cooled before it can be mixed with the bonding materials. This cooling is essential, as the warm sand will cause trouble with excessive drying off, or crusting of the mixed core sand. Two methods are employed to cool the silica sand after drying and prior to mixing. If the hot sand were put into hoppers it would retain its heat for many hours, and the cooling capacity required would be out of all reason. The sand must be cooled before it is placed into hoppers. A circular revolving drum may be used with cool air passing in the opposite direction to the flow of sand. The most economical method is that combining cooling and handling of the sand in one operation, and is known as the suction lift system. The suction lift system consists of a length of piping connecting the outlet of the sand drier and the dry sand storage hoppers. By means of fans the sand is lifted and drawn through these pipes. The air carrying the sand has the necessary cooling effect. The pipes lead into a cyclone, or collector, which causes the sand to fall into the storage hoppers in a steady stream.

The dry sand storage hoppers should be placed above the oil-sand mixers, and be so arranged that measured batches of sand can be fed into

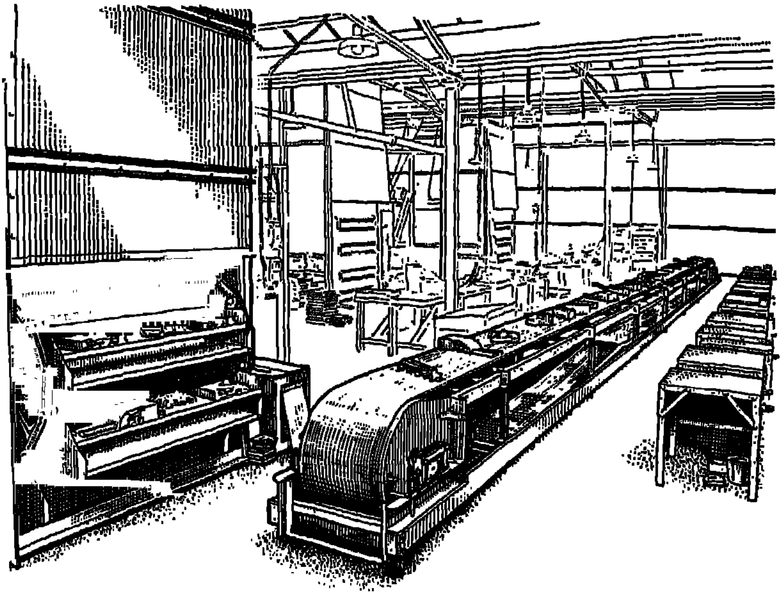


FIG. 9.67. *A steel-band conveyor for taking cores to and from the core stove (shown on the left of the shop).*

the oil-sand mixers. The handling of the mixed oil-sand can be achieved by one of the following methods:

(1) Rubber belt conveyor,
(2) Bucket type conveyor,
(3) Batch trucks and bogies.

The layout of plant in the core shop governs the method which is employed to deliver the mixed sand to the coremakers. This is described more fully in Chapter 13.

MECHANICAL HANDLING OF CORES

Before Stoving. Mechanical handling can be applied after the cores are made and have to be transported to the core stoves, as follows:

(1) Use of batch-type stoves and a portable core rack, which is placed alongside the coremaker's bench; the coremaker places the cores, immediately they are made, on the rack. When completely full, the rack is conveyed by means of a special bogie to the core stove, and an empty rack placed alongside the coremaker.

(2) Transportation of cores by means of roller tracks (conveyors). This method consists of an efficient roller track being placed in a position connecting the coremakers' benches to the core stoves. The cores must

be placed on suitable smooth plates, which have bearing faces which will run smoothly along the roller track. A slight incline must be allowed on the roller track; the danger of using a roller track is that green cores collide and distortion occurs due to bumping. A roller track is used where there is not a straight run between the coremakers' benches and stoves.

(3) Steel band conveyors. The ideal method of transporting green cores to the core stove is by means of a steel band conveyor, as shown in Fig. 9.67. As its name implies, this conveyor consists of a sliding steel band which passes over a series of skids and rollers.

(4) Pendulum, or suspended-tray, type conveyors. Coremakers' benches may be arranged alongside a pendulum conveyor, and the cores when made conveyed on the pendulum to the point at which they are lifted off into the stoves. In some cases, the pendulum conveyor may pass through a horizontal type of drying stove.

The conditions which govern the type of conveyor to be chosen are the building and the equipment already in the shop. If a new shop is being considered it is always an advantage to have benches laid out in a direct line in front of the core stoves so that a steel band conveyor can be utilized. A steel band conveyor, in conjunction with automatic loading and unloading of the core stoves, supplies the ideal method of handling cores from a mass-production core shop.

After Stoving. When removing cores they will be too hot to handle without some protection to the hands. A cooling time will be required before the cores can be handled for examination and dressing, ready for the moulder. It is desirable that, as cores are taken from the stove, they are placed on a conveyor, preferably of the pendulum type, which, if correctly arranged, will allow the necessary cooling time before they arrive at the inspection and dressing department. It is essential that each core should receive proper and careful inspection, as one quite small core which is incorrect may be the cause of a large, complicated and expensive casting being scrapped.

Mechanization in the core shop has led to the introduction of female labour to coremaking, and it has been proved, during the last few years, that suitably trained female operators can give excellent results in the production of cores.

Chapter 10

MOULDING MACHINES

THE mechanization of the foundry is dealt with in another chapter, but it is considered that, as moulding machines play such an important part in modern practice, a complete chapter on their general principles, uses and limitations will be of assistance. There are many types and makes of machines, all of which have their particular application. There is no universal machine which will efficiently make every type of mould; the fallacy that this was the case did exist until recently, but with the advance of mass-production methods in the foundry, the true values of the various types of machine have been more fully appreciated.

Another misunderstanding which was formerly prevalent was that the introduction of moulding machines into foundries detracted from the art of moulding and, consequently, would cause a decline in a very long-established industry. In fact, the use of machines in the foundry has made it possible for the industry to compete on a sound basis with other trades, such as steel and brass stamping, Bakelite and similar plastic moulding.

As its name indicates, a moulding machine is a machine for producing moulds by applied mechanics. The objects are to eliminate manual fatigue and remove the necessity for skill in producing a good mould. With the simpler types of machines these objects are only partially attained, and a certain amount of energy and skill are still necessary to obtain efficient outputs. It will be appreciated that the production of a mould, as detailed in Chapter 8, entails ramming the sand to a correct density and then removing the pattern from the mould; thus, broadly speaking, we have two main operations to perform.

STRAIGHT DRAW MACHINES

Dealing firstly with the simpler types: Fig. 10.1 shows a hand-operated pin lift, or straight draw, machine. A single-sided pattern plate is employed, and this is fixed to the table of the machine with locating pins. In the case of a double-sided pattern plate, a false frame, or box, must be used to enable the pattern plate to be mounted rigidly on the machine table. The pattern plate having been fixed securely to the table, the moulding box is placed on the locating pins and filled with sand. This

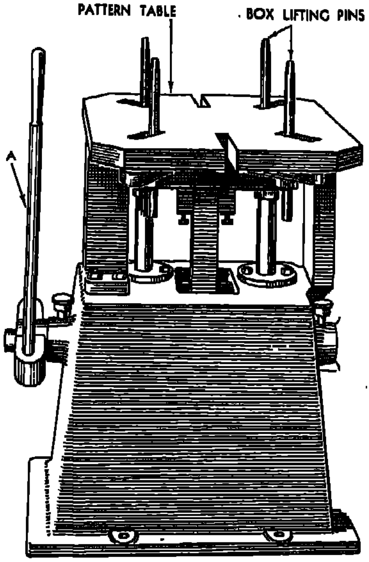


Fig. 10.1. *Simple form of moulding machine. Lever A operates the box lifting-pins.*

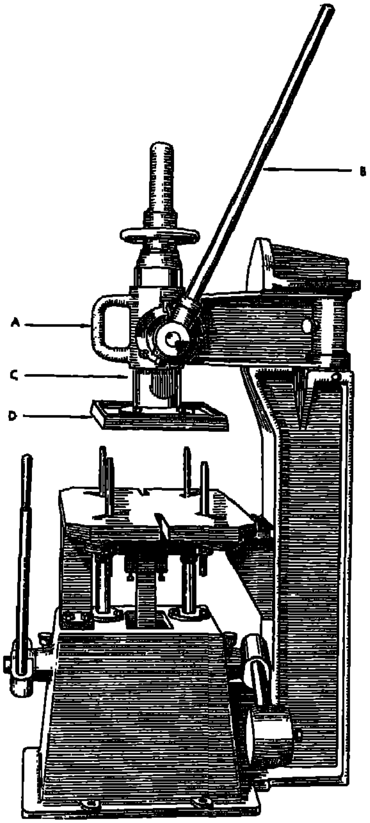


Fig. 10.2. *Hand-operated squeeze and pattern-strip machine: (A) swinging arm, (B) squeezing lever, (C) squeezing plunger, (D) presser plate.*

is then rammed up in accordance with the normal moulding method, and strickled off. Any runners, or risers, or venting should then be made, after which the machine is ready to perform its part of the operation. The lever A (Fig. 10.1) which lifts the box off the pattern, is moved slowly and at the same time the operator raps the table or pattern plate with a mallet. Rapping is continued until the mould has been drawn clear of the pattern, when the lever is operated more quickly until the maximum movement has been obtained. The mould will remain in the topmost position without the lever being held, thus enabling the operator to remove the mould off the machine on to the floor, or conveyor. The operating lever is then returned to its original position, and the machine is ready to deal with the next mould.

Fig. 10.2 depicts a similar machine, but fitted with column and squeezing arm and plunger. With this type a considerable amount of the hard work is avoided, because the squeezing mechanism eliminates hand ramming. Pressure is applied to the mould by a small crank movement with a long leverage, thus making it possible for a normal man, without undue exertion, to apply 2 to 3 tons pressure on to the sand. This alone, in most cases of straightforward, simple patterns, is sufficient to obtain a correct ramming density of the sand. The area and depth of the box are, of course, important factors and, as a rough guide, it can be said that 20 to 30 lb. per sq. in. pressure on the mould is necessary to produce correct ramming.

Another very important factor which must be considered is the shape and depth of the pattern. Fig. 10.3 shows a box-shaped pattern, which is very straightforward from an ordinary moulding point of view, but which would not be easy to deal with on any type of plain squeeze machine. The reason for this is that with a large area of pattern near to the top of the box part, the whole of the pressure will be taken on the uppermost part, leaving the side walls and the face of the mould quite soft. Therefore, when this type of job has to be handled it will be necessary for hand ramming to be done before using the squeezing mechanism.

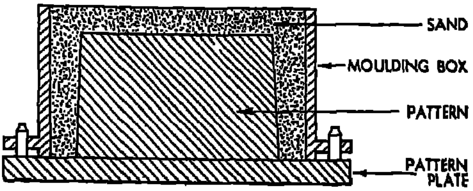
SQUEEZE PLATES

As already explained, the machine shown in Fig. 10.2 is similar to that previously described, with the addition of a squeezing member. A indicates the swinging arm which carries the squeeze plate, and can be rotated so that it is moved clear of the table and moulding box to facilitate sand loading, etc. B is the lever which operates the squeezing plunger C. The presser plate D is normally made to fit inside the box part to be dealt with, and approximately ⅛-in. clearance between the inside box dimensions and the plate should be allowed. This enables the whole of the pressure from the squeezing head to be effective on the mould.

If the plate is larger than the box, some of the pressure is withheld from the mould by the edges of the moulding box. It is normal, with this form of machine moulding, to employ a sand frame (Fig. 10.4), which should have the same internal dimensions as the box part. Suitable lugs, or brackets, are required to locate the frame quickly and accurately. The depth of this frame will vary according to the pattern being moulded, but, as a rough guide, it should be approximately 25 per cent of the depth of the moulding box; that is, with a 4 in. deep part, a 1 in. deep frame, and with a 6 in. deep part, a 1½ in. deep frame would be used.

The correct depth of frame should enable the operator to squeeze the mould so that the sand is level with the top of the moulding box, thus obviating the necessity for strickling off or making up. The procedure for operating this type of machine is as follows: the moulding box is located on the pins in the pattern plate, and the sand frame positioned. The box

FIG. 10.3. *An example of a pattern which is unsuitable for plain squeeze-type machines.*



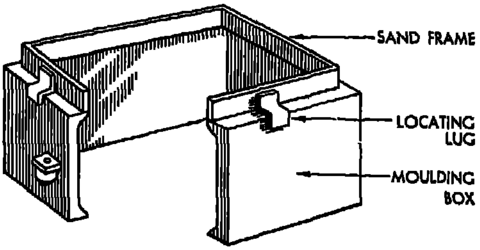
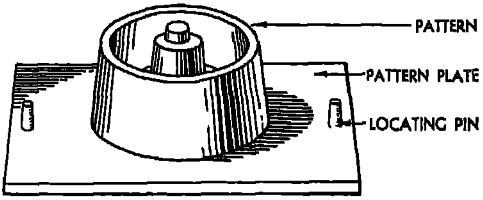


FIG. 10.4. *Sand frame normally used for machine moulding to measure the correct quantity of sand. This type has the same internal dimensions as the box part.*

is then filled with sand, and any preliminary tucking or ramming made; the sand should then be levelled off with the frame, the swinging arm moved into position over the mould, and the lever B pulled forward and downward. The lever is then returned, the swinging arm moved back, and the sand frame taken off the box part. The mould is then ready for stripping, which operation has already been explained as fully as possible in the paragraph dealing with the hand-operated pin lift machine.

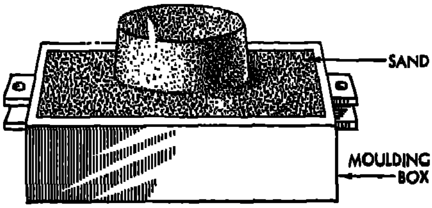
PATTERNS

The machines described above have their limitations in regard to the type of pattern with which they will deal. It will be appreciated that with both types the mould is lifted upwards from the pattern; this permits



(Left) FIG. 10.5. *Typical deep cod pattern which has to be dealt with on mass-production lines. In no circumstances would this pattern be suitable for the straight-draw or pin-lift type of machine.*

(Right) FIG. 10.6. *Example of mould with cod or sand projection. With this type it is essential to use only the best type of sand possessing a high green bond strength.*



only simple types of patterns to be dealt with. Fig. 10.5 shows a typical pattern which would not be suitable for the straight draw or pin lift type of machines. Not wishing to confuse the reader, it is felt that some explanation here may be useful. The green bond strength of the sand has a very important bearing on the point, and no hard-and-fast rule can be adopted. It will be understood that if we have a pattern which, in moulding, leaves a cod, or projection, of sand 3 in. diameter by 2 in. deep (Fig. 10.6), this, in a poor quality sand, will not permit the mould to be lifted off the pattern by the method already detailed. If, however, the particular foundry has in normal use a sand with a high green bond strength, it is possible to make satisfactory moulds from this pattern with the straight draw-type machine. Also, where this form of work is a very low percentage of the total it is possible to adopt the method of sprigging, or bradding, the mould in difficult places. When deep and intricate patterns are in the majority a turnover machine is suggested.

TURNOVER TABLE

Fig. 10.7 illustrates a simple form of turnover machine. A indicates the turnover table which rotates between the trunnion brackets B. The mould receiving platform, marked C, is operated by lever D. The procedure for ramming the mould is exactly as has already been described. When the mould is ready to draw from the pattern, the box clamps are brought into position to secure the moulding box to the pattern plate. The whole table, plate, and box are then rotated (Fig. 10.8); the mould platform is raised with the operating lever, and the table-locking screws E are

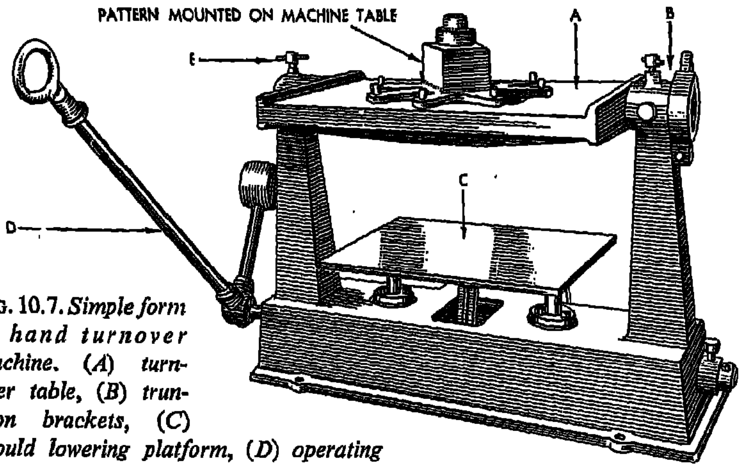


FIG. 10.7. *Simple form of hand turnover machine.* (*A*) *turnover table,* (*B*) *trunnion brackets,* (*C*) *mould lowering platform,* (*D*) *operating lever,* (*E*) *one of two table-locking screws.*

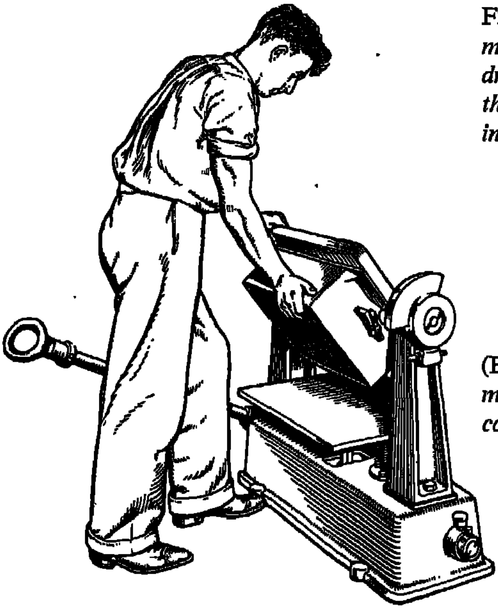
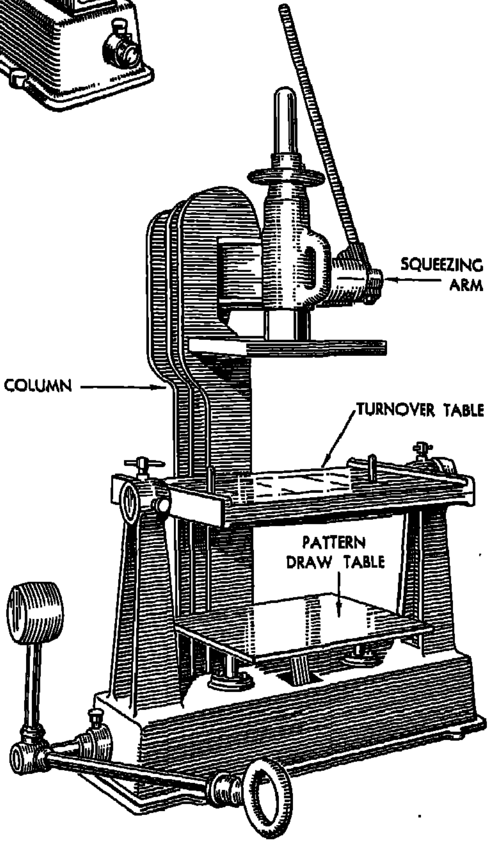


FIG. 10.8. *Mould being rotated on machine ready to effect pattern draw. After the mould is placed on the loading platform and secured in position it is rapped and vibrated as required.*

(Below) FIG. 10.9. *Turnover moulding machine fitted with a column, squeezing arm and plunger.*

tightened to obviate any pattern movement while the mould is being drawn and the box clamps removed from the box. The table of the machine is then rapped and vibrated while the platform control lever is slowly lowered, the speed being gradually increased until the mould is completely free from the pattern. The mould is then carried away and the turnover table reversed and the machine is ready for the next operation. Fig. 10.9 shows a similar machine, but one fitted with a column, squeezing arm, and plunger; as already explained, this additional equipment facili-



tates the ramming of the mould, the remaining operations being as just described.

SNAP FLASK MOULDING

While dealing with hand-operated moulding machines, a plain squeeze machine, specially suitable for dealing with snap, or slip, flask moulding, is worthy of mention. Fig. 10.11 portrays this type of plant, A being the swinging arm, and B the lever which operates the squeezing plunger C; the presser plate, marked D, should be of suitable dimensions for the flask to be used as will be explained later. E shows the table of the machine, and F the work bench. A word on the purpose and uses of snap flask moulding may be helpful. Firstly, owing to the lightness of the pattern and flask equipment it is possible to use junior, or female, labour. Generally speaking, patterns suitable for snap flask moulding are simple and have very little depth, which feature also lends itself to the employment of the less skilled operator. Secondly, the cost of equipment for quite high efficiency in output is relatively low. Thirdly, box handling before and after casting is minimized.

Fig. 10.10 shows a snap flask, which is in effect a pair of strongly constructed wooden boxes complete with locating pins and lugs, but, unlike the moulding box, the snap flask is split diagonally with hinges in one corner and locking clips in the opposite corner; also, at the joint face of each half-flask are small projections on which rest the binding bands. Fig. 10.12 shows the binding bands, the top pressure board with runner cup, and the bottom board. The pattern equipment for snap flask moulding is normally a double-sided plate which can either be as cast and dressed, or a flat plate with the necessary patterns matched and mounted on each side. Lightness of this pattern plate is essential, and aluminium is used extensively in most foundries for the purpose.

It is necessary to deal with snap-flask moulding procedure in some considerable detail. The two halves of the flask, each having been fastened with their locking clips, are assembled with the pattern plate between them (Fig. 10.13) and placed on the machine table (E, Fig. 10.11). That which is to be the bottom or drag part of the mould should be in the uppermost position at this stage. Next, a binding band which should be an easy fit is inserted into the flask, resting on the projections next to the pattern plate. This half of the flask is then filled with sand and strickled off flush. The bottom board, which should be approximately ¼ in. smaller than the inside size of the flask in each dimension, is placed in position and then bedded in slightly by hitting on the battens with the hands.

The next operation requires a little practice. The whole of the flask

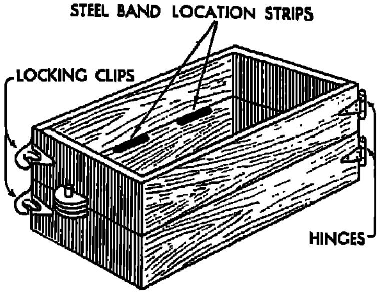


FIG. 10.10. *Pair of snap flasks for snap moulding.*

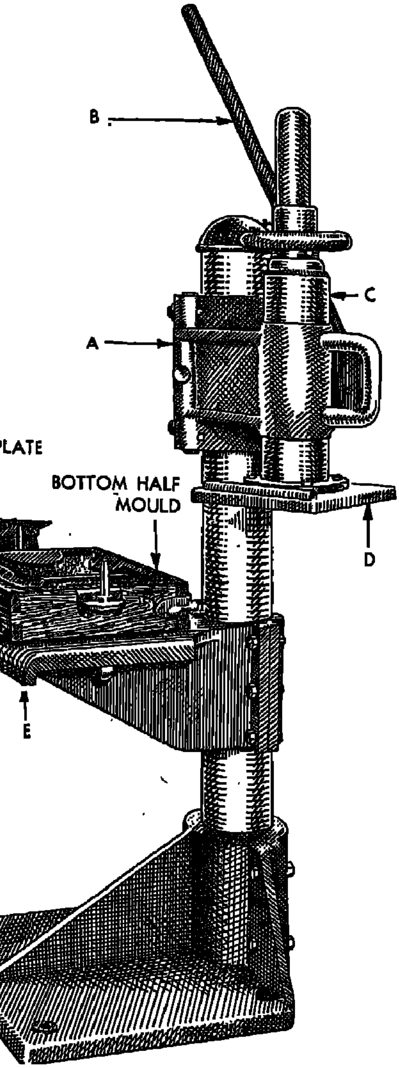


FIG. 10.11. *Hand-operated squeeze machine without pattern-stripping equipment. (A) Swinging arm, (B) squeezing lever, (C) squeezing plunger, (D) presser plate, (E) machine table, (F) bench.*

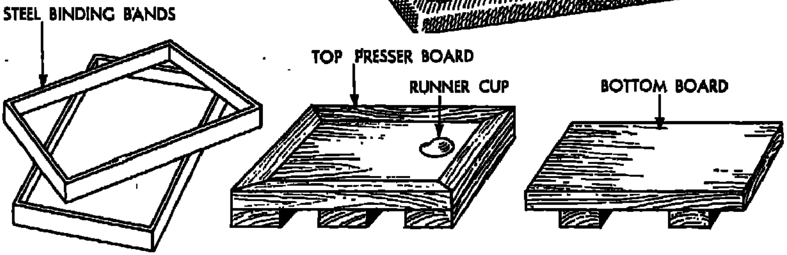


FIG. 10.12. *Equipment required for snap-flask moulding.*

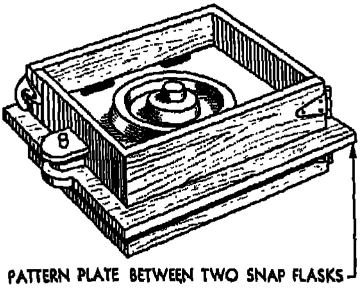
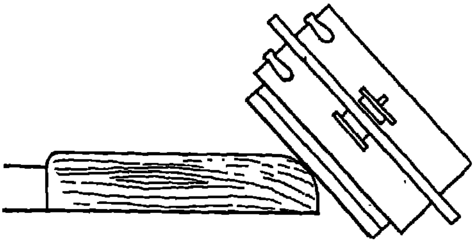
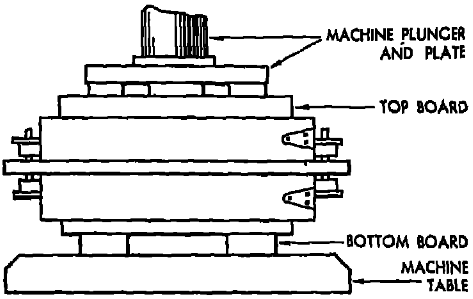

B
PATTERN PLATE BETWEEN TWO SNAP FLASKS

FIG. 10.13. *Snap flask with pattern plate assembled and locked in position.*

assembly is picked up and rolled over (Fig. 10.14) using the round edge of the table of the machine. The top half of the flask is dealt with in a similar way; i.e., binding band insertion, filling with sand, strickling off flush, and placing the top board, which should be of similar dimensions to the bottom board, in position. On this top board will be noticed a strip, or beading, round the edge. This serves two purposes: firstly, it helps to make the mould hard at the edges; secondly, it leaves a flat surface which is essential for the flat type of weight which is used for casting the mould. When the top board is in position the squeezer head of the machine is moved over the snap flask and the lever (B, Fig. 10.11) moved to effect the necessary pressure on the mould. It will be appreciated that, in this manner, both halves of the mould are being pressed at the same time (Fig. 10.15). It is necessary to ensure that the snap flask is approximately central on the work table, so that both battens of the top board are subjected to equal pressure. When the mould has been pressed, the arm is moved aside, and the top board withdrawn.

As has been mentioned, a runner cup, or pouring basin, is mounted on this top board which should match with the ingate on the pattern plate. At the bottom of this runner cup the necessary





(Upper) FIG. 10.14. *Snap flask being rolled over on machine table.* (Lower) FIG. 10.15. *Both halves of the snap flask with the pattern plate being squeezed together.*

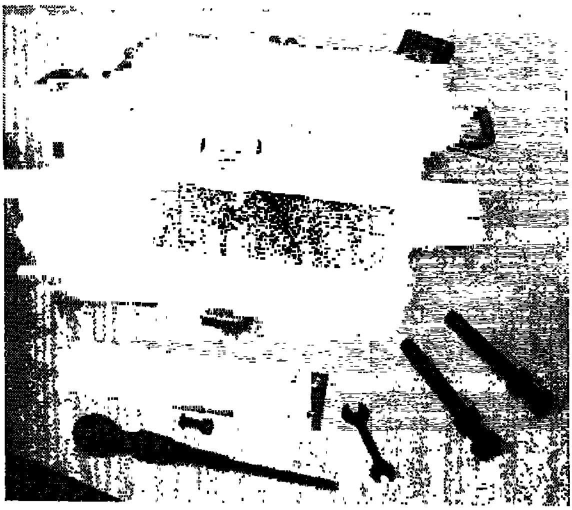


FIG. 10.16. *A pop-off flask. The diagonal corners part sufficiently to allow the tapered flask to be withdrawn upward.*

down-gate should be made with a metal tube. The pattern plate, which projects beyond the flask, should be rapped or vibrated, and the top half of the flask lifted off by hand and then transferred to the work bench. Then the pattern plate is drawn and set aside. The bottom part of the moulded flask is now resting on the machine table; any cores which are necessary should be inserted, and the top part closed on to the bottom flask. The clips of both halves of the flask are opened, and the whole hinged apart to allow for removal from the mould, which is then left resting on the bottom board. The mould is carried away on the bottom board and placed on the floor or conveyor, ready for weighting and casting.

POP-OFF FLASKS

For some years now there has been used in the United States, and more recently in Great Britain, equipment known as the "pop-off flask." Its function and principle is similar to the snap flask, but it utilizes a tapered flask. It does not open fully with a hinge, but the two diagonal corners part sufficiently to allow the tapered flask to be withdrawn upward, leaving the tapered complete mould on its bottom board. Special aluminium or cast-iron jackets must be provided and it is necessary for these to be a reasonably accurate fit on to the tapered mould to enable pouring to be accomplished successfully without the metal being forced out at the joint line.

Figs. 10.16 and 10.17 illustrate the pop-off flask and also a mould with its appropriate pouring jacket.

POWER SQUEEZE MACHINES

In addition to the hand-operated presses, or squeeze machines, there are many different types of plain power squeeze machines. Pneumatics, hydraulics, and electrical solenoids are among the principles in general use for the operation of squeezing machines, and any of these types will deal with snap flask moulding quite efficiently. Plain squeeze type machines are used a great deal more in the United States than in this country. This is probably because in the U.S.A. they view the problems of production right through the whole picture, and, in consequence, the foundry receives full consideration in design and pattern equipment. This enables them to make use of simple-type machines to obtain really high outputs. Plain squeeze moulding machines are used also with ordinary box parts and fixed pattern plates.

Fig. 10.18 illustrates a pneumatic squeeze machine. As will be appreciated, this type of machine is simply a press, which obviates the fatigue of ramming the sand either manually or by means of the hand squeeze machine, which, although assisting, still relies on manual strength for its effective pressure. With the pneumatic plain squeeze machine, normally a simple valve is the only control and can easily be manipulated by the younger foundry workers. A pneumatically operated plain squeeze machine

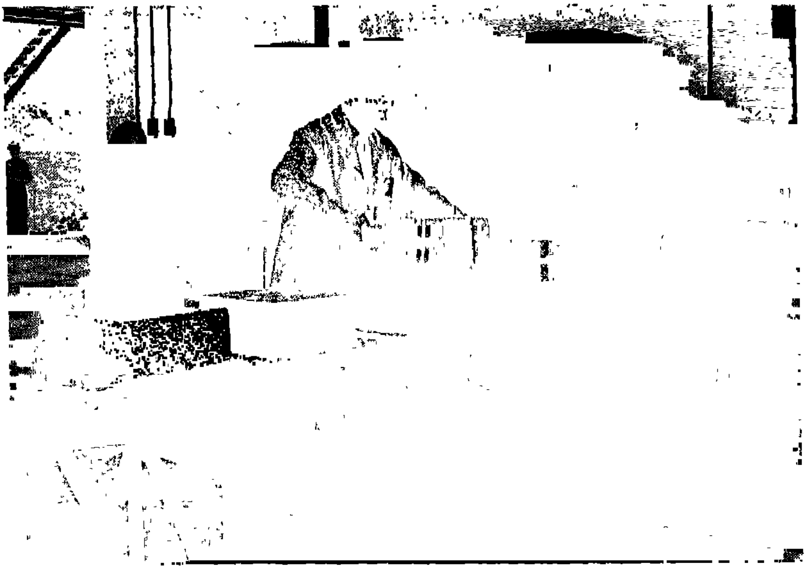
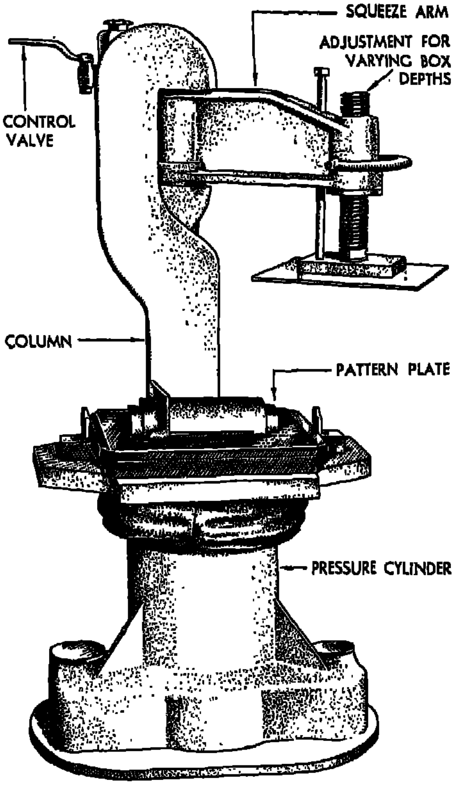


FIG. 10.17. *Pop-off flasks in use, showing tapered mould after withdrawal of flask and (left) a mould in its pouring jacket.*

FIG. 10.18. *Pneumatically operated plain squeeze-type moulding machine.*



is usually quite simple in its construction, consisting of a main body which also forms the cylinder, a piston to the top of which is fixed the pattern table, and a press plate, or head, against which the pressure is made. The size of the cylinder is of an area that, when operated with the normal air-pressure supply of a foundry, usually 80 to 100 lb. per sq. in., it will give a resultant pressure on the mould of 25 to 35 lb. per sq. in. The hydraulically operated machine is very similar in construction, one important difference being the dimensions of the cylinder and piston, as, normally, hydraulic mains pressure is 750 lb. to 800 lb. per sq. in., and thus the size of the cylinder unit is small compared with the pneumatic machine. The operation and function of both types of machine are, in most respects, identical.

Yet another medium of power for plain squeeze machines has more recently been employed, the electrically operated press. The pressure with this type of machine is obtained by the use of the electric solenoid principle, which consists of a suitable winding, or field, round a core which is attached to the table of the machine. When an electric current is passed through the winding, the core is deflected, carrying the table upwards to make effective pressure against the squeezing head. Fig. 10.19 shows such a machine. The reader will appreciate that on those mentioned as plain squeeze machines, pattern stripping or box lifting mechanisms are usually provided, and are normally operated by the same power medium as the squeezing portion of the machine. This is not always the case, as in some instances a machine may be fitted with a hand-operated stripping arrangement.

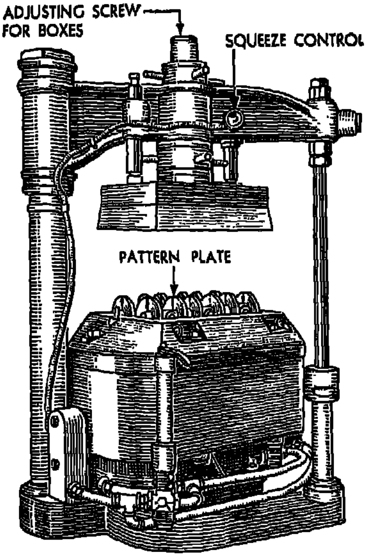


Fig. 10.19. *Electrically operated squeeze-type moulding machine.*

Usually, to obtain a smooth and even stripping movement, oil-controlled pistons, or plungers, are employed. A very useful addition to the plain squeeze machine is the down sand frame.

DOWN SAND FRAME

As previously explained in this chapter, sand in excess of the box depth has to be provided so that when the sand has been compressed it is flush with both top and bottom faces of the box. The down sand frame is a permanent fixture on the machine which allows the desired surplus of sand, and also has the additional advantage of rendering more simple the use of moulding boxes with bars; this point will be dealt with later. Fig. 10.20 shows the arrangement of a down sand frame. It will be seen from this that the surface of the pattern plate is below the face of the box. This dimension can be adjusted according to the particular job and box being dealt with. The procedure is as follows:

Sand is filled into the box in the normal manner, but a top frame is not employed; instead, the loose sand is strickled off level with the top of the box. The presser head is then moved over the box, and pressure is applied. The whole down sand frame assembly, box pattern and sand then move upwards until the top face of the box meets the presser head. The box itself cannot travel any farther, but the pattern plate continues to be pressed upwards until it comes to a predetermined stop, which is level with the bottom face of the moulding box. Thus, the sand is compressed to the exact depth of the box, giving a level joint on both the top and bottom of the box part. As previously mentioned, this form of sand frame facili-

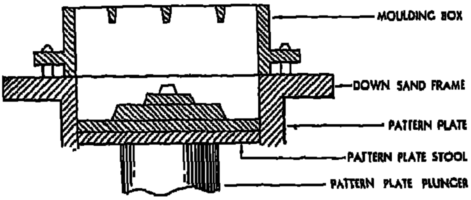


Fig. 10.20. *Down sand frame arrangement. Note that the face of the pattern plate is below that of the moulding box. This dimension can be adjusted according to the particular job and box being dealt with.*

tates the use of boxes with bars, and it will be appreciated that when the box is filled with sand the compression takes place by the sand below, the box being pressed upwards, thus forming the sand up to and around the bars. The other type of sand frame, already described, is placed on the top of the box, and the sand is pressed down and partially away from the bars in the box.

In many cases a machine fitted with a down sand frame has no lifting mechanism. As already explained, the plain squeeze machine is suitable only for comparatively shallow work, and as the pattern plate moves away from the face of the mould when the pressure is removed, this amount of movement is often quite sufficient to make the effective pattern draw. A particularly ideal application, in use both in this country and on the Continent, is the manufacture of single cast-iron piston rings. Normally, these are up to ¼ in. deep in varying diameters, and, consequently, the amount of pattern movement required is small. This type of job also lends itself to a very efficient labour-saving method which is known as stack moulding.

STACK MOULDING

Normally, in order to produce one casting, or a complete set of castings, from a pattern plate, two half-boxes are employed; thus, for 12 such sets of castings, 24 half-boxes would have to be machine moulded. To produce 12 sets of castings, using the stack moulding method, only 13 half-moulds are necessary. The procedure is as follows:

A box is rammed up without any patterns and placed on the floor, joint side uppermost. Twelve half-moulds are then made on the machine and stacked on top of each other on the flat box already referred to. A suitable pouring down-gate should be provided on the pattern plate, which leaves the necessary hole through each half-mould. Thus, when the metal is poured into the top half-mould it flows right to the bottom, filling that part first and filling the remaining moulds one by one until, in the normal manner, the pouring basin is full. It should be remembered that with this method, reasonably hard ramming is necessary, as, obviously, some strain is caused on the sand in the lower moulds by the weight of molten metal above. Fig. 10.21 will show the method of stacking and providing a runner gate.

The particular job referred to is one where the whole of the pattern is in one half-box part; this is commonly known as a flat back job. Shallow work, which by its shape has to have split patterns, can also be stack moulded. This is termed matched stack moulding. The principle is similar, but great accuracy is necessary in the pattern department. Therefore, the deeper or more intricate part of the pattern should be mounted on the

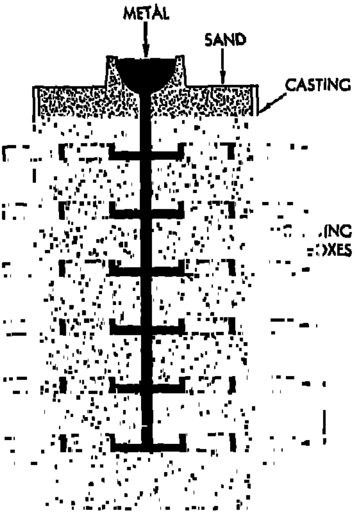


FIG. 10.21. *Stack moulding as used for the mass production of single cast piston rings.*

machine table, the other half being mounted on the presser plate. Exactly the same procedure is used for moulding, except that certain stopping off of runners to the lowest and uppermost mould is necessary to prevent wastage of metal. With this type of work, box closing pins are needed for each half-mould stacked. Finally, not the least important point with this method is the considerable saving in floor space that can be obtained for any given number of castings.

PLAIN SQUEEZE ROLLOVER MACHINES

In addition to the machines mentioned, there are in use plain squeeze rollover or turnover machines. These are mostly employed on specialized work as, normally, a rollover machine is associated with deeper and more intricate patterns, and the plain squeeze machine does not give sufficient ramming facilities to permit this to be accomplished. Fig. 10.22 shows a machine of the electric type which turns over the pattern plate and mould. On this machine there is a down sand frame. The box is placed in position and filled with sand. A plate, or board, is then placed on the top of the box and clamped in position. The whole of the table is rotated and the pressure applied by a ram, which moves upwards from the underside of the machine. The clamps which have held the box and board are then released, and the

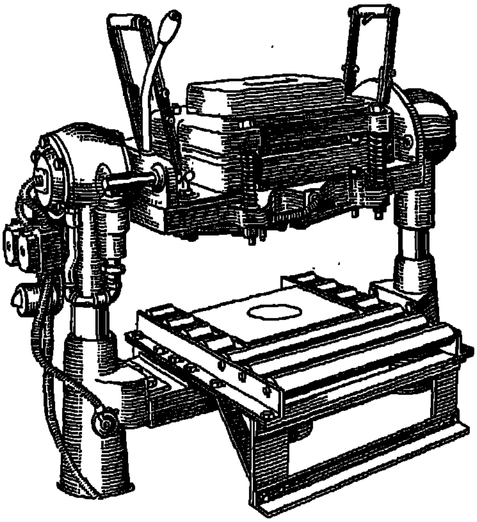


FIG. 10.22. *Electrically operated turnover machine.*

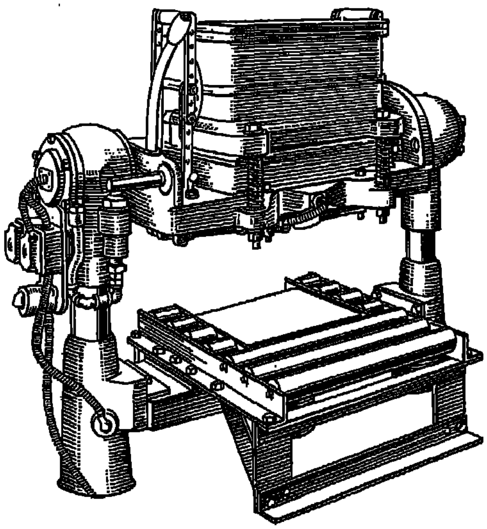


FIG. 10.23. *Box and board held in position with clamps.*

ram lowered, taking with it the half-mould ready for removal from the machine. Figs. 10.23–25 should make this quite clear. There are other similar machines which apply the pressure to the mould before turning over, and usually have the rams situated in their heads; thus, bottom boards, or plates, are unnecessary, as the sand is in a compressed condition before the box is rotated.

JOLTING MECHANISM

So far this chapter has dealt with machines which rely on pressure alone for their effective ramming of sand, and, as already explained, have a limited scope. Probably the most universal machine in present use is one which is fitted with a jolting mechanism. This movement is fitted and incorporated in machines of many different types and sizes. The principle is that by lifting the whole of the pattern plate, box and sand, and allowing them to fall again on to an anvil, or rigid

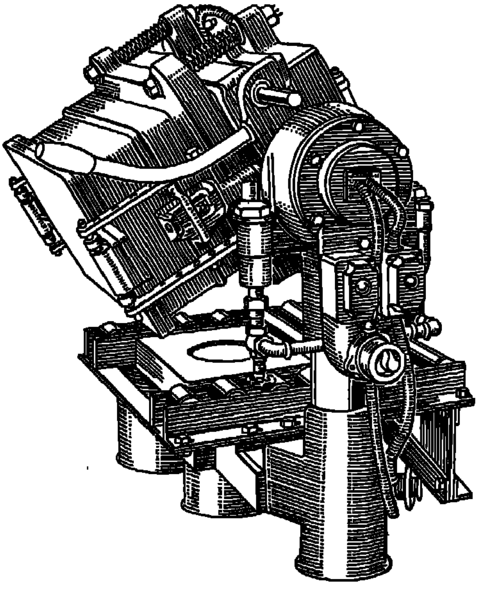


FIG. 10.24. *Table of machine being rolled over, while the clamping device is holding the box in position.*

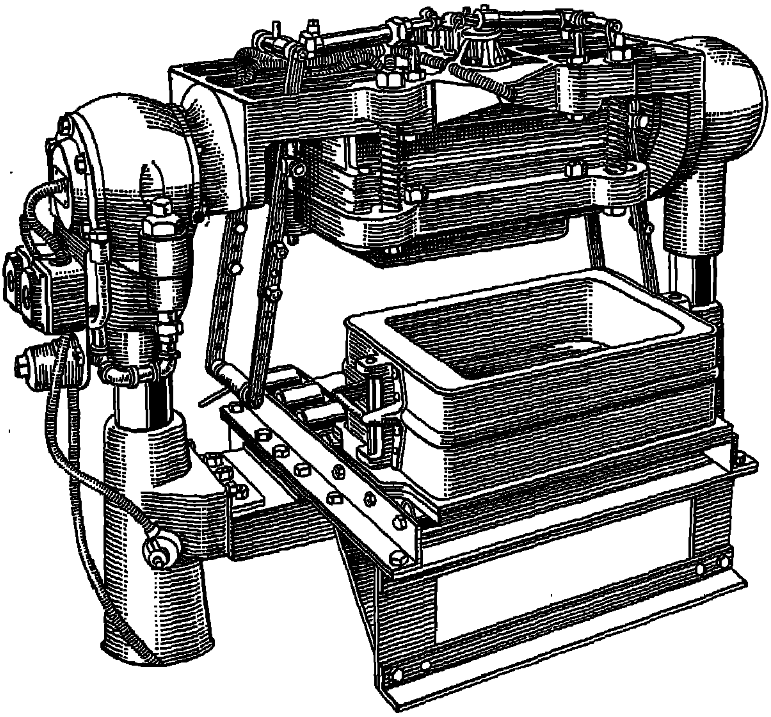
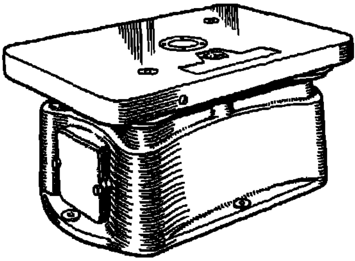


Fig. 10.25. *Plain squeeze rollover machine, showing how the mould is drawn from the pattern by the downward movement of the squeezing piston.*

part of the machine, the sudden arrest of the downward movement of the sand causes it to pack, and thus results in effective ramming. Generally speaking, the majority of jolt machines are pneumatically operated, although there are still a few hand-operated types. Some years ago, machines with jolting mechanisms which were operated mechanically were also manufactured. Fig. 10.26 shows a pneumatic plain jolt machine, its only function being effectively to ram the sand in the box. Usually this type of machine is employed where small quantities are required of medium or large work. The procedure is as follows:

The pattern (whole pattern if flat back, or half-pattern if split) is registered on the table and the box placed in position and partly filled with sand. The jolting mechanism is then started, and more sand added to the box until it is quite full. When sufficient jolting has taken place the machine is stopped and the top of the mould is flat rammed. This flat ramming by hand is necessary as the last 2 in. to 3 in. of sand will not pack sufficiently hard to enable the mould to be handled with safety. The mould

FIG. 10.26. *Pneumatic plain jolting machine for ramming the sand in the moulding box.*



is then removed from the machine with the pattern still in the sand. The pattern is then drawn by hand in the normal method and returned to its location on the machine table. When whole or flat back patterns are used it is unnecessary to locate the pattern accurately, but, of course, if split patterns are used it is necessary to have dowel, or similar, location, to ensure an exact matching of the half-moulds.

Normally, plain jolt machines of the larger sizes are sunk into pits to bring the table of the machine an inch or so above floor level; this facilitates box handling and sand loading. The construction and design of a plain jolt machine is simple, but robust. It comprises a main housing, which has integral with it the main cylinder; on the top part of this housing are provided strips, or pads, on which the jolting impact takes place. These pads or strips are sometimes made of fibre, or hardwood, as with two metal faces constantly taking the jolting impact, the tendency is for crystallization of the metal to take place. The cylinder is fitted with a piston to which is attached the table of the machine. The size of the piston and cylinder bore should be such that the area expressed in square inches is one-fortieth of the maximum jolt load to be handled.

Usually, the larger plain jolt machines are controlled with a jolt valve. This mechanism ensures a maximum of efficiency in jolting impact, as it very accurately controls the flow of air in and the exhaust out. Also, with a jolt valve-controlled machine it is possible to adjust the length of piston stroke, thus altering the impact force, according to the work which is being made. It will be appreciated that with a large jolt machine lifting a combined weight of 10 tons or more and allowing it to fall approximately 4 in., very considerable foundations are necessary. In an endeavour to combat this problem efforts have been made to perfect the shockless jolt machine.

Shockless Jolt Machines. The principle of this design is that it has an intermediate member between the main housing and the piston, which member is supported on springs of very heavy proportions. The object of this is that the middle member, which also forms the cylinder, is forced down, and the piston forced up when air is admitted and the jolt valve changes. The cylinder is then exhausted, the piston and table commence to fall; at the same time the centre portion of the machine is forced upwards by the spring and the impact blow takes place without any, or very little, of the shock being transmitted to the main housing. The one main difficulty with this type of machine is that the box and sand have a tendency to bounce owing to the force of the impact being artificially produced. It is difficult to govern the speed of the movement of the two members to produce a blow similar to that which is obtained by the gravitation of a weight from any given distance. Although this problem has not been completely overcome, there are many similar machines being used to good advantage in the foundry industry.

Probably the most popular machine is one employing all the principles previously mentioned, namely, a machine which is fitted with jolting mechanism, squeezing cylinder and head, and pattern-drawing mechanism (Fig. 10.27). The power supply is compressed air. With this machine and the right equipment, all skill and fatigue are removed, so that female labour can be successfully employed. The chief points of interest are the main housing, which embodies the squeezing piston, and also the jolt cylinder and piston to the top of which is fixed the pattern table. On to this table is fitted a vibrator. Below the main housing is the pattern draw cylinder and piston to which is fixed the lifting shafts carrying the four box lifting pins. At the back of the main housing is fixed a vertical column which carries the swinging squeeze arm. The complete cycle of operations of the machine is as follows: The box having been positioned on the locating pins in the pattern plate and the top sand frame placed in position, it is filled with sand, and the jolt mechanism operated by moving lever A, Fig. 10.27. When sufficient jolting has taken place the lever is returned to its normal position. The squeeze arm is then moved over the mould and the lever B pulled forward, which causes the whole table assembly to move upwards, thus squeezing the sand against the presser plate. When this lever is moved back, the mould and table return to their normal positions.

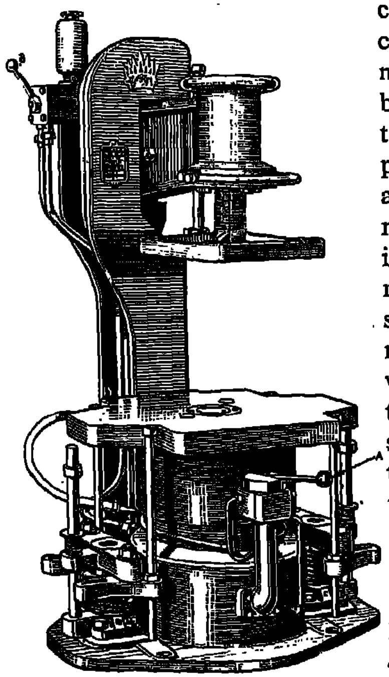


FIG. 10.27. *Pneumatically operated jolt-squeeze pattern-drawing moulding machine.*

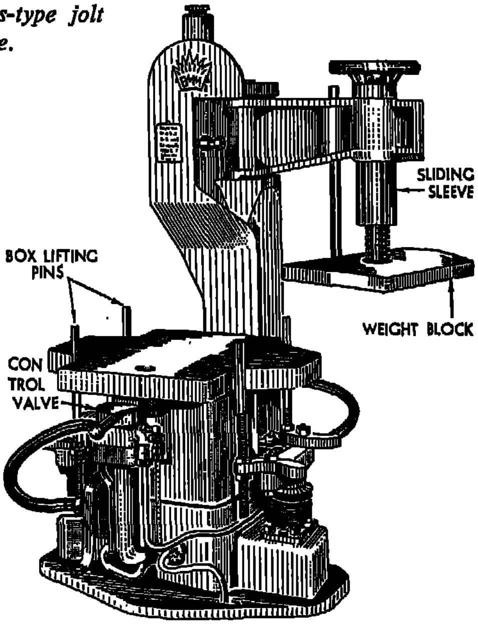


FIG. 10.28. *Pneumatic shockless-type jolt pattern-stripping machine.*

So far we have effectively rammed the mould, and it remains to draw the pattern from the mould. The lever A is again operated, but in the opposite direction to that required for the jolt. This causes the vibrator to function and assist the pattern leaving the mould. At the same time the four lifting pins move upwards, starting very slowly and increasing in speed as the upward movement continues. When sufficient vibration has taken place, that is, normally, when the pattern has drawn about $\frac{1}{2}$ in., the lever A is moved to the next position, and this carries the pins to the top of their stroke and causes the vibrator to cease. The sand frame is then removed and the mould is ready to transfer to the conveyor or floor.

When conveyors are used the moulding machine operator should be positioned as closely as possible to these so as to obviate fatigue and waste of time in carrying the finished half-mould any greater distance than necessary.

Some years ago a different form of this type of machine was introduced. In appearance it is similar to that just described, but is fitted with a shockless jolt mechanism. As previously mentioned, shockless jolt machines are prone to cause a bouncing of box and sand; this machine was, therefore, designed to obviate this trouble, and has generally proved very effective. In the swinging arm of the machine shown in Fig. 10.28 a loose plunger is arranged, carrying the presser plate. This plate is much heavier than the normal presser plate, as it is the weight factor which is important. The principle is as follows:

The box having been located and filled with sand, the operating valve lever is moved, which allows the whole unit, consisting of table, jolting anvil, box, etc., to be carried upwards by the large coil spring, which is inside the main housing. The top of the loose sand bears up under the presser plate which, in turn, carries up the loose plunger. Thus, the weight of the presser plate and plunger are resting on the sand. The jolting mechanism is then operated, and the effect of the weight on the sand, while the mould is being jolted, restricts the bounce to such an extent as to make it practically negligible. At the same time, the action of the additional weight on the top of the sand has the beneficial effect of ensuring a very hard mould. It should also be noted that no flat ramming or squeezing is necessary as the top portion of the sand is rammed sufficiently hard. The one disadvantage is that it does not permit any tucking or hand ramming to be done after jolting, and, therefore, is a machine which is suited to straightforward patterns. The only remaining operations for stripping the mould from the pattern are similar to those already described for the preceding machine.

The modern trend towards mechanization and automation is very marked in the foundry trade, automation being especially applicable to the mass production of moulds. Naturally, where high outputs from a single pattern are in demand, uniformity of production with as little fatigue as possible is desirable. Complete automation has been accomplished in Great Britain, the United States and also on the Continent, but such vast plants can only be fully utilized where a company has production runs of 100,000 or more of one given part. There has been more recently an attempt to break down these vast automatic plants into smaller, more manageable units, and this has met with considerable success—to the benefit of many more founders whose runs off any particular pattern are in the region of 1,000 or upwards.

Fig. 10.29 shows a single-operator automatic machine. This is basically a shockless simultaneous jolt squeeze machine with pattern stripping arrangement having flanged rollers instead of the conventional lifting pins. The purpose of these rollers is that the finished mould can be rapidly removed from the vicinity of the machine and thus the machine operator can immediately proceed with his next half-mould. On one side of the machine are fitted flanged rollers similar to those which are fitted to the lifting frame, while on the other side is ordinary gravity-roller track for conveying the empty half-boxes to the machine. Both the flanged rollers and the gravity rollers are set at the same height as that to which the frame lifts for the pattern draw; thus the moulding box can be rolled on to the machine and rolled off with minimum effort.

TURNOVER MACHINES

We now come to what are probably the most useful machines in general use today, namely, the turnover and rollover machines. These it will be necessary to divide into two separate groups, as they differ quite considerably in design and application. Fig. 10.30 illustrates a well-known type.

FIG. 10.29. *Automatic single-operator jolt-squeeze machine, with pattern-stripping arrangement having flanged rollers instead of lifting pins.*

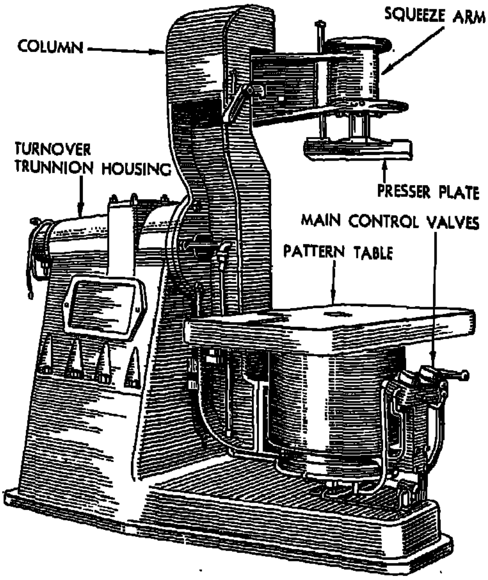


FIG. 10.30. *Pneumatically operated turnover jolt-squeeze and pattern-draw moulding machine.*

The baseplate on this carries a housing through which is located the turnover shaft. To this shaft is fixed a large, heavy chain sprocket. Housed in the baseplate are the two turnover cylinders and piston which are depressed alternately when the valve, mounted at the front of the baseplate, is operated. To the top of each piston is secured the end of the heavy roll chain which engages with the sprocket. Thus, when the pistons are ope ated by the control valve, the chain is moved, causing the sprocket and the trunnion shaft to rotate. To one end of the trunnion shaft is coupled the main column carrying the main cylinder at one end and the swinging arm and presser plate at the other extremity. The cylinder unit contains a main squeeze piston which houses the jolt piston; to the top of the jolt piston is fixed the pattern table, to which is attached the vibrator. The swinging arm is capable of being rotated clear from the table of the machine and the presser plate is mounted on a large screw allowing adjustment for varying depths of box. Furthermore, attached to the main cylinder unit is the main control valve box.

The operation of the machine is as follows:

The box having been located on the pattern plate and filled with sand, the jolt mechanism is operated by the jolt control valve in the front of the machine. When sufficient jolt has been effected, the jolt valve lever is returned to normal. The sand is then levelled off roughly by hand and the swinging arm moved over the mould. The main squeezing valve is operated which carries the table, pattern plate, box and sand up to the presser plate. The turnover valve on the baseplate of the machine is then moved which causes the whole of the cylinder, column, and swinging arm assembly to rotate 180 deg. Thus, the pattern plate is now above the box and sand which has been moulded (Fig. 10.31). It should be noted that there is no necessity for box clamps to be used as the

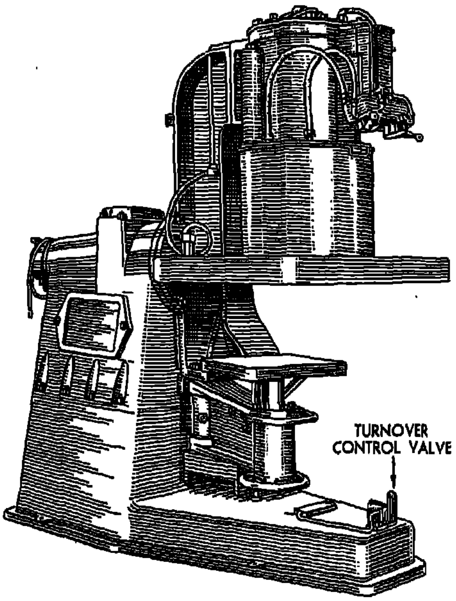


FIG. 10.31. *Turnover jolt-squeeze machine in pattern-draw position.*

squeezing pressure, which is several tons, is adequate to clamp the box to the pattern plate. The next operation is to remove the pattern from the mould. This is accomplished by operating the pattern draw and vibrator valve controls, the vibrator being discontinued when sufficient pattern strip has been effected. When the pattern has been fully drawn the mould is resting on the presser plate. It is then removed to the floor, or conveyor. The turnover valve is again operated, which returns the whole machine to its normal working position.

The type of machine just described is most suitable for the production of the smaller ranges of castings and, generally speaking, its limitations are only reached when the size of mould to be produced becomes too heavy for two men to carry away from the machine. Special mechanical lifting arrangements have been made in many foundries in an effort to facilitate the use of a fast-type machine on heavy work, and are, in a measure, quite successful, but if this additional mechanization is not available, the increased speed in production of a heavy mould can quickly be lost if delay arises through having to wait for lifting cranes to remove the mould from the machine.

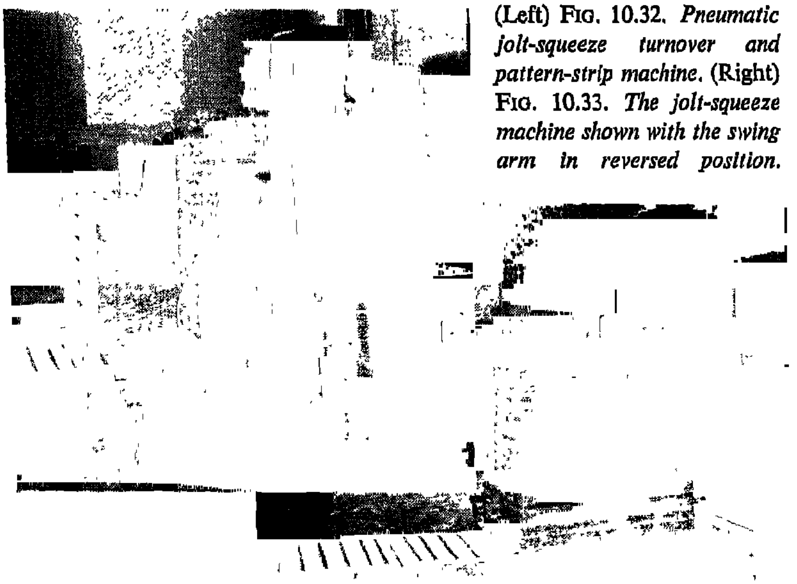
Having in mind the many advantages of a turnover machine, more recent developments in design have enabled larger moulds to be produced quite satisfactorily with this type of equipment. Figs. 10.32 and 10.33 show a modern pneumatic jolt squeeze turnover and pattern strip machine which is equipped with jolt timing device, pneumatically operated swing arm and pneumatically interlocked swing gate and roller conveyor. The fitment of a jolt timer to modern machines is of considerable advantage because, with closer control of prepared sands, it is very desirable that the same ramming technique should be applied to each mould being made from the same pattern. A further feature which became necessary when producing larger turnover machines was pneumatic operation of the swing arm; as machines were built to take larger work, manual operation of the swing arm became increasingly difficult and heavy.

As can be seen from Figs. 10.32 and 10.33, the interlocked hinged portion of the roller conveyor is in a vertical position when the machine is normal. It will also be seen that the presser head has rollers attached on each side of it; these are retractable so that the loose presser board or plate is pressed against the flat presser plate and not against the rollers. After the mould has been completed and the machine inverted, the hinged portion of the swing gate is brought down into position pneumatically (Fig. 10.33). After the pattern has been withdrawn the pneumatic cylinders controlling the two sets of rollers on the front and back of the presser plate lift automatically and thus the finished half-mould on its board rolls out on to the swing gate and gravity-roller track. The hinged portion of the swing gate is interlocked with the machine and the machine cannot turn back until the swing gate has returned to its vertical position, which leaves a clear path for the whole of the machine to turn back through 180 deg. The control valve which swings the arm aside is then operated, rendering the machine ready for producing the next half-mould. With this type of equipment it is quite practicable to produce, at a very high rate of output, medium to fairly heavy work in moulding boxes measuring 48 in. long by 30 in. wide by 15 in. deep.

ROLLOVER MACHINE

This machine is most suitable for dealing with the heavier type of repetition work, and although not as fast in producing the actual mould, its construction lends itself to a more efficient output. Figs. 10.34 and 10.35 show this type of machine. In the first illustration the box is seen being lowered on to the pattern table, while Fig. 10.35 shows the box filled with sand. The construction of this type of machine is as follows:

The jolting cylinder and piston are housed as a separate unit on the necessary foundation. Fixed to the top of the jolting piston is a table which supports the pattern table of the machine. On this table are positioned two pneumatically operated clamps for securing the mould and board while rolling the machine over. The pattern table is carried by two



(Left) FIG. 10.32. *Pneumatic jolt-squeeze turnover and pattern-strip machine.* (Right) FIG. 10.33. *The jolt-squeeze machine shown with the swing arm in reversed position.*

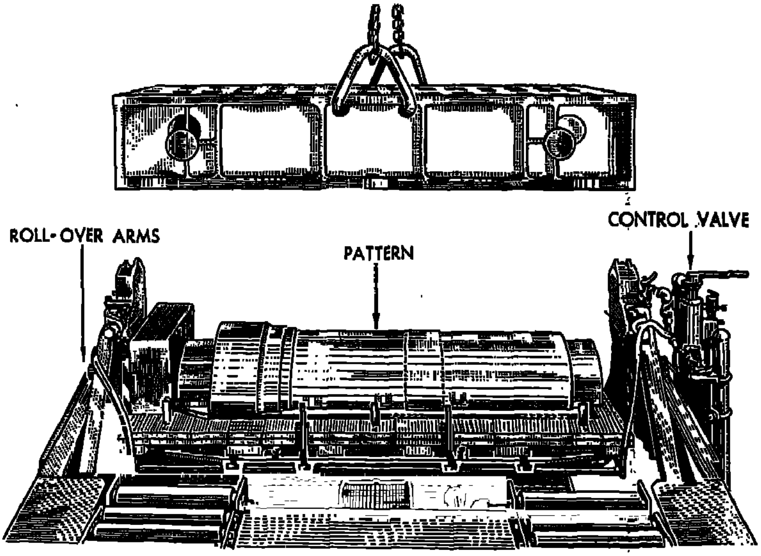


FIG. 10.34. *A large pneumatic jolt rollover and pattern-strip machine. The box is being lowered into position by means of pulley blocks.*

arms which are attached to the main rollover shaft. This shaft has a cranked centre portion which is joined by a connecting rod to an oil-operated piston and cylinder. At the opposite side of the machine to the jolting unit are situated the pattern draw cylinder and piston. To the top of the piston is fixed a table which has a levelling bar fitted on each longitudinal edge. Operating procedure is as follows:

The machine table, to which the pattern plate has been secured, should be resting on the jolting unit as seen in Fig. 10.34. The box having been located and filled with sand, as in Fig. 10.35, the jolt valve control is operated. This causes the machine table, box and sand to be jolted, the impact taking place on the upper portion of the jolt cylinder unit. With larger types of work, the necessary length of time for jolting may vary between 10 and 60 sec., also, in certain classes of work, it is probable that the moulding box will need to have additional sand added, as with deeper boxes sufficient sand cannot be piled above the box in the initial loading to complete the mould.

After sufficient jolting has taken place, the top of the mould has to be flat rammed, as, on this type of machine, there is no squeezing, or pressing, arrangement. A flat, substantial board is then placed on top of the mould and the pneumatic clamps operated to secure the mould to the machine table. The rollover control is then moved and the two arms

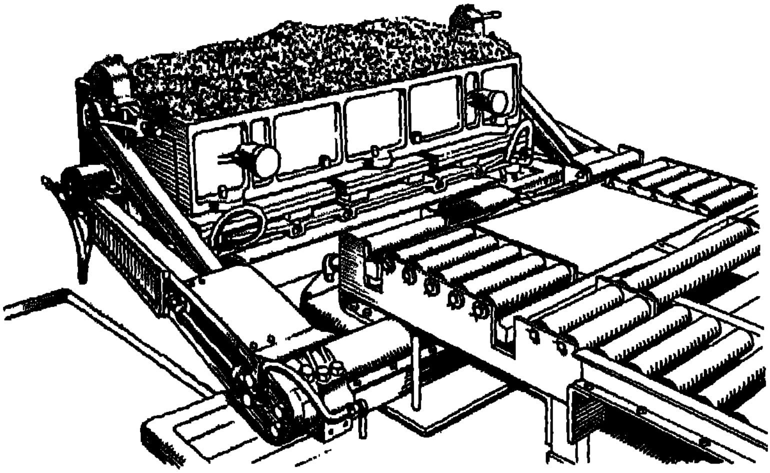


FIG. 10.35. *Machine with box in position filled with sand and ready for jolting.*

carrying the table, pattern plate, box and sand, hinge over and the mould is then inverted over the pattern draw unit. The vibrator, fitted to the machine table, is started; at the same time the pattern draw piston and table are raised, and the levelling bars make contact with the wooden board. The box clamps are then released and the pattern draw portion lowered away, which carries the mould downwards with it (Fig. 10.36). As seen in the illustrations, the machine has a roller conveyor track, and the mould resting on the board is deposited on this track as the pattern draw piston and table pass through it. The mould can then be moved away from the machine and the machine table rolled back again to its starting position ready to receive the next moulding box. It will be appreciated that this method of ready mould removal from the machine enables the machine to be more usefully employed, as there need be no delay in proceeding with the next mould when the previous one has been deposited on and moved down the roller track.

SAND SLINGING

As will have been appreciated, there are two fundamental principles for sand ramming, i.e. jolting or jarring, and squeezing or pressing. These are also undertaken separately or in combined forms. There is, however, a further medium for packing or ramming sand into a moulding box known as sand slinging. Fig. 10.37 illustrates a machine which is universally known as a sand slinger. The function of this plant is to throw sand with a fairly considerable force into the moulding box, which has been placed round the pattern, and by that means alone quite effective mould hardness is attained. The construction of this machine is such that the sand is emitted from a small hopper which is positioned at the extremity of a hinged arm, and so allows the ejected sand to be thrown into the whole box area as the arm is moved. The sand is carried to the top of the machine by means of a bucket elevator, it is then allowed to fall into a band conveyor which passes through the arm, and then into the impeller, which finally ejects the sand from the hopper. The motive power is usually two or three electric motors, one on each of the conveying arrangements. From the motors are driven the necessary shafts, sprockets, etc. Generally speaking, the sand slinger is most useful where large, heavy castings are in repetitive demand. There are two types in general use: the stationary type, which has a fixed position in the foundry, and the mobile type, which can be moved about the foundry as a complete unit and placed in a convenient position to deal with large moulds, which frequently have to be partially moulded in the foundry floor.

In the preceding paragraphs an attempt has been made to describe the more generally known types of machines, together with some indication of their purposes and limitations. There are many other specially built machines which are designed to accommodate a specific type of casting, where these castings are required in very large quantities. No useful

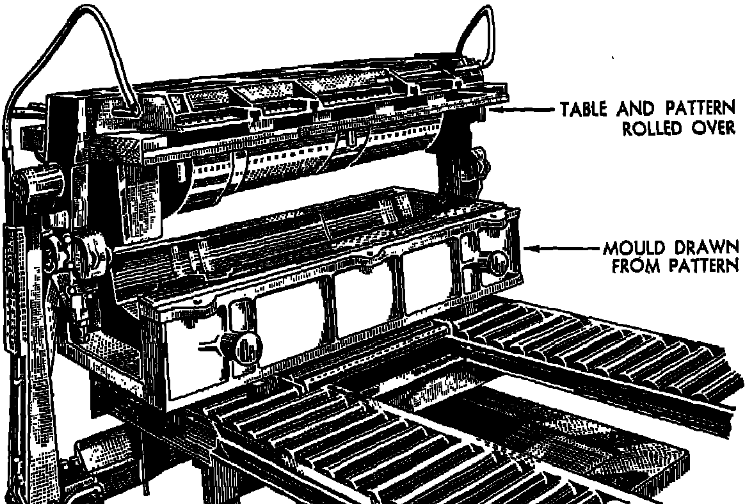


FIG. 10.36. *Jolt-squeeze machine in the inverted position, with the mould having been withdrawn.*

purpose would be served in attempting to describe these many and varied specially built types, but a few words on the choice of a machine will be helpful to some readers.

CHOICE OF MACHINE

As already emphasized, there is no universal type of machine which is suitable for every class of work to be undertaken, and the choice of the right machine requires the consideration of many points. To mention a few of these, there is, firstly, the question of the number of castings of one type which have to be produced in any given period, and whether or not the particular job is one which recurs regularly. Assuming that the foundry considering the installation of moulding machines has had no previous experience in mass-production methods, they would be wisely guided if they installed one of the general-purpose machines for dealing with small number contracts of, say, 1,000 castings off a certain pattern. This would then enable them to gather the necessary experience and also apply for other small quantity contracts, with the knowledge that the general purpose machine would deal with any work within its size. Alternatively, if this same foundry secured a contract calling for 100,000 castings of one type with repeat orders to follow, they should consider the installation of the most suitable machine for fulfilling that particular job only.

PATTERN EQUIPMENT

Another problem which confronts many founders when considering the initial installation of moulding machines is the existing pattern equipment. To this question there is really no satisfactory answer, as patterns which have been used for loose moulding are, in the majority of cases, too badly worn to mount on to moulding machine pattern plates. There are, of course, certain exceptions to this, and it is quite often found that foundries change from plate moulding to machine moulding as a natural advancement.

With plate moulding, as already explained in Chapter 8, the patterns are nearly always mounted on both sides of a single plate, and to accommodate such plates on most types of moulding machines necessitates the use of a frame which will house the underside of the pattern plate which is not in use. Some care is necessary with this method as very often the original pattern plate has been made as thin as possible to facilitate manipulation by hand methods, and if a thin plate is mounted on a frame and placed on a machine of the squeeze or press type, it is almost certain that when the pressure is applied to the mould, the plate will be distorted, resulting in a cracked or broken mould. To overcome this, supporting

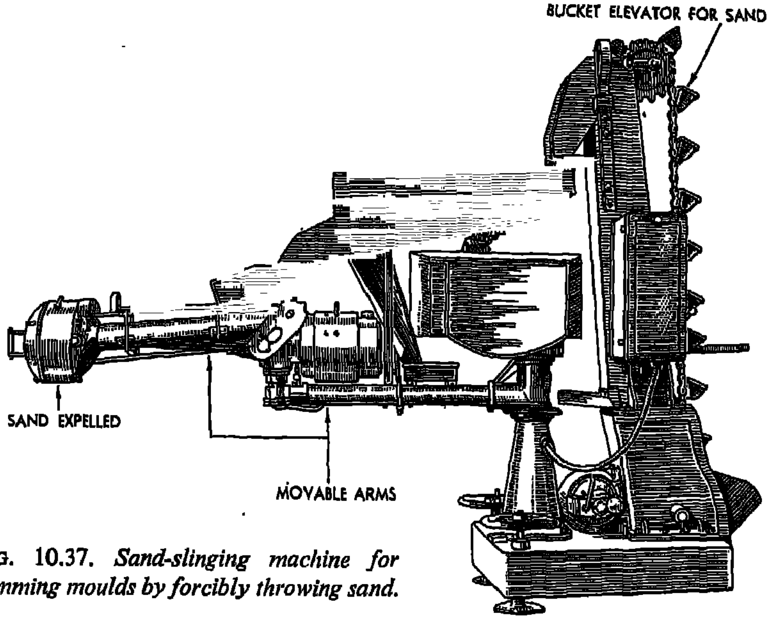


FIG. 10.37. *Sand-slinging machine for ramming moulds by forcibly throwing sand.*

struts can be fixed to the pattern plate in suitable positions. This ensures that it remains rigid when under pressure.

Another very important point in dealing with pattern equipment for machine moulding is that of high-class finish. A good loose pattern or floor moulder can, with the roughest of wooden patterns, produce first-class work by virtue of the fact that quite a large percentage of his skill is in finishing the mould after the pattern has been withdrawn. With a moulding machine used under proper conditions, patterns should be such that no mould finishing whatsoever is necessary, and to attain this end considerable effort and experience are necessary in the pattern-shop. This particularly applies to metal patterns. In most pattern-shops where the work is for loose-pattern moulding few metal patterns are handled. Although the problem might appear as being only to reproduce a similar shape in metal instead of wood, nevertheless it is a point which requires very careful study and consideration. Another factor which concerns the pattern-shop in producing correct machine moulding patterns is that core prints and core boxes have to be used to a much greater extent than with loose patterns. With floor, or loose pattern, moulding the moulder finds no difficulty with projecting bosses or overhanging flanges, but these present major problems for machine-moulded, mass-produced castings, and, therefore, all patterns should be made so that they can be withdrawn from the mould without drawbacks or loose pieces.

BOX PARTS

Yet another problem confronting the foundry installing its first moulding machine is that of suitable box parts. With loose-pattern moulding, as already explained, it is an old practice to use boxes which have a maximum amount of clearance on the locating pins. Obviously, with boxes of this type used on any machine which jolts, the box would be free to move in respect of the pattern and result in a badly rammed mould, and also most probably produce a mis-matched casting. The joint faces of moulding boxes used for loose-pattern moulding need not be as accurate as for machine moulding. But boxes with uneven joint faces will rock and tip on the machine when being jolted and the irregularity of the box face will detract from obtaining a clean pattern draw, owing to the fact that the box cannot be supported evenly, and thus is not secure on the pattern stripping mechanism. Boxes used on moulding machines for the mass production of castings should be periodically inspected and remachined if necessary. In one very large mechanized foundry in this country, box parts are checked and examined after each mould produced in them. Although this may appear to be a waste of time, it does by no means plan out to be so in actual practice—inspection and repair save much trouble in addition to speeding up production.

MOULDING TIME

In summing up the foregoing remarks on the choice of a suitable machine, it is felt necessary again to repeat that a moulding machine will only ram the mould and draw the pattern. The reason for emphasis being laid on this particular point is that so many users of machines in this country tend to think in terms of how many moulds an hour this or that type of machine will produce instead of calculating how rapidly the machine can be supplied with boxes and sand, and how quickly the moulds can be removed from the machine. Of course, this applies only if the right type of machine is being employed for the specific work, and the pattern equipment and boxes are suitable. Here is one isolated, but very good example, of what this means. Earlier in the chapter the plain squeeze down sand frame type of machine was mentioned, and its particular aptitude for the manufacture of single-cast piston rings was pointed out. The actual time to mould a half-box of approximately 16-in. diameter and strip the pattern would not exceed 5 sec., but the box location on the machine, filling with sand and removing the mould might take anything up to 30 sec. Thus, we have a machine which, by virtue of the fact that it cannot be fed fast enough, is capable only of part of its maximum output. The 30 sec. quoted is based on the assumption that the sand is hopper fed. If, however, the sand has to be manually fed to the machine this figure might readily be 120 sec. It follows that the slowest part of the operation governs the ultimate output of the machine.

ADVANTAGES OF MOULDING MACHINES

There are factors other than quick production which are advantageously gained by the use of moulding machines. To mention only some of these, firstly, uniform density of mould hardness, resulting in a higher standardization of casting finish. Secondly, all runners, ingates and risers can be moulded, which is quite a considerable point. As dealt with elsewhere in this book, the correct size of gating is very important, and, obviously, difficult to reproduce manually with accuracy on individual moulds. When the correct size and type of gate have been established for machine-moulding practice, and mounted on the pattern plate, a correct reproduction with each mould is the result. Yet a third factor is the correct shape and size of the finished casting. Very often with hand-moulded work, castings gain in size and weight owing to excessive rapping having been made by the moulder to enable him to draw the pattern cleanly from the mould. With a machine-operated pattern draw this enlargement of the mould size is not possible, and results in castings which are true to shape and size. This is a very important factor where castings have to be built up into assemblies without machining, such as in the case of certain boilers, stoves, cooking-ranges, etc. A fourth and quite important advantage is the long life of the pattern equipment. Loose patterns made of mahogany, or pine, rapidly deteriorate owing to the fact that they have to be rapped and spiked so that they can be drawn from the mould.

It should be added that by no means the least important factor in the installation of any machine is the ability of the executive responsible to ensure that the installation receives the necessary proper attention. In the past, many foundries have installed plant which, in a short time, has become redundant. It is not always the case that the machines they have obtained have been of the wrong type. Very often founders have purchased machines hoping that by their installation all their problems of production would be automatically overcome. This is far from being so, and when a machine is installed, many people have to put in a considerable amount of effort before the results which are desired can be attained.

Chapter 11

MODERN MOULDING DEVELOPMENTS

THE SHELL-MOULDING PROCESS

THE shell-moulding process originated in Germany during the Second World War and received its early publicity in this country in 1947. It has also been called the "C" process, after Herr Croning, its German inventor. The principal characteristics of the process are the production of castings with a high standard of surface finish and dimensional accuracy, a high rate of production from a small floor space, and a marked reduction in the amount of material, such as sand and box parts, which has to be handled. Nearly all the common casting alloys can be cast by the shell-moulding process, although probably the largest field of application is with stainless steel and the copper alloys, and to a lesser extent grey cast iron and malleable iron. Some typical castings are shown in Figs. 11.1 and 11.2. Low carbon steels cast in shell moulds are liable to show depressions in the upper surface of the casting, the reason for which is still obscure.

In conventional sand moulding the sand grains are bonded by clay, whereas in shell moulding the clay is replaced by a synthetic resin. The resin is usually in the form of a fine powder of 200 or 300 mesh grading which is mixed with the sand; but it is becoming increasingly common to use a mix in which the individual sand grains are coated with the partly cured resin. As will be seen later, this has a number of advantages. Whether precoated sand or a mixture of powdered resin and sand is employed, the mix as it stands will not aggregate, and for this to occur heat has to be applied so that the resin can soften, flow and eventually bind the sand grains together to form a hard mass. In the first stage of curing this heat is supplied by the pattern, which must therefore be of metal.

Fig. 11.3 shows the successive steps of shell-making. The pattern is first heated to a temperature of 200 to 220 deg. C. and a stripping agent which will facilitate the subsequent removal of the shell from the pattern is sprayed on. The resin-sand mix is then allowed to fall, i.e., is dumped, on to the pattern from a height of about 10 in. to 12 in. Adequate packing of the sand grains necessitates the sand falling from this height, and in addition considerably more mix is dumped than will be needed to form

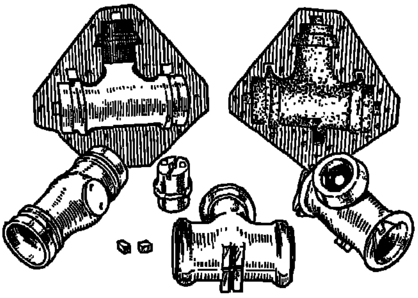


FIG. 11.1. *Aluminium castings, weighing 12 lb., made in shell moulds and incorporating shell cores.*

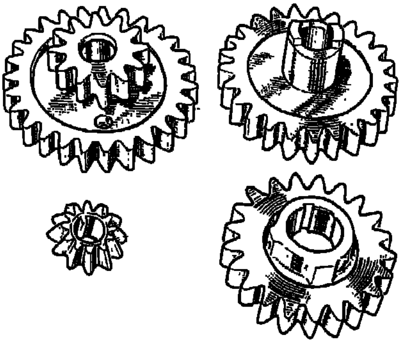


FIG. 11.2. *Cast iron gearwheels made in shell moulds.*

the shell. The hot pattern plate causes the resin to soften and flow, carrying sand grains to the face of the pattern. This is termed the investment stage. Chemical changes are taking place in the resin during this stage, transforming a chain-like structure into a three-dimensional network. After about 20 seconds' investment, the change is only partially complete and has progressed most adjacent to the pattern face and to a lesser extent further away from it. At a point about ¼ in. from the pattern face insufficient heat has penetrated, due to the low thermal conductivity of the sand, for any softening of the resin to occur; and if the pattern plate is then inverted the shell of sand, bonded by the partly cured resin, adheres to the pattern plate while the remainder of the mix falls back into the container and is available for subsequent use.

The partly cured shell, still adhering to the pattern, is then placed in an oven for final curing. This is carried out at about 400 deg. C. and may take up to two minutes. The temperature of neither curing nor investment is critical. Lower temperatures need longer investment and curing times, but have the advantage that the distribution of heat is more uniform. When curing is complete the shell should be golden brown in colour. It is relatively hard and rigid and can be stripped from the pattern, most commonly by means of spring-loaded ejector pins which pass through the pattern plate. Two such shells form a complete mould and are fixed together, often by gluing, before being poured. During pouring the heat of the metal chars the resin on the face of the shells, destroying the bond. But, again because of the low thermal conductivity of sand, such charring is slow to penetrate beyond the casting face. Even there, it seems likely that the first stage of breakdown is the formation, for a limited time, of a liquid which seals the mould pores; and it is because of this that shell-moulded castings are characterized by an excellent surface finish,

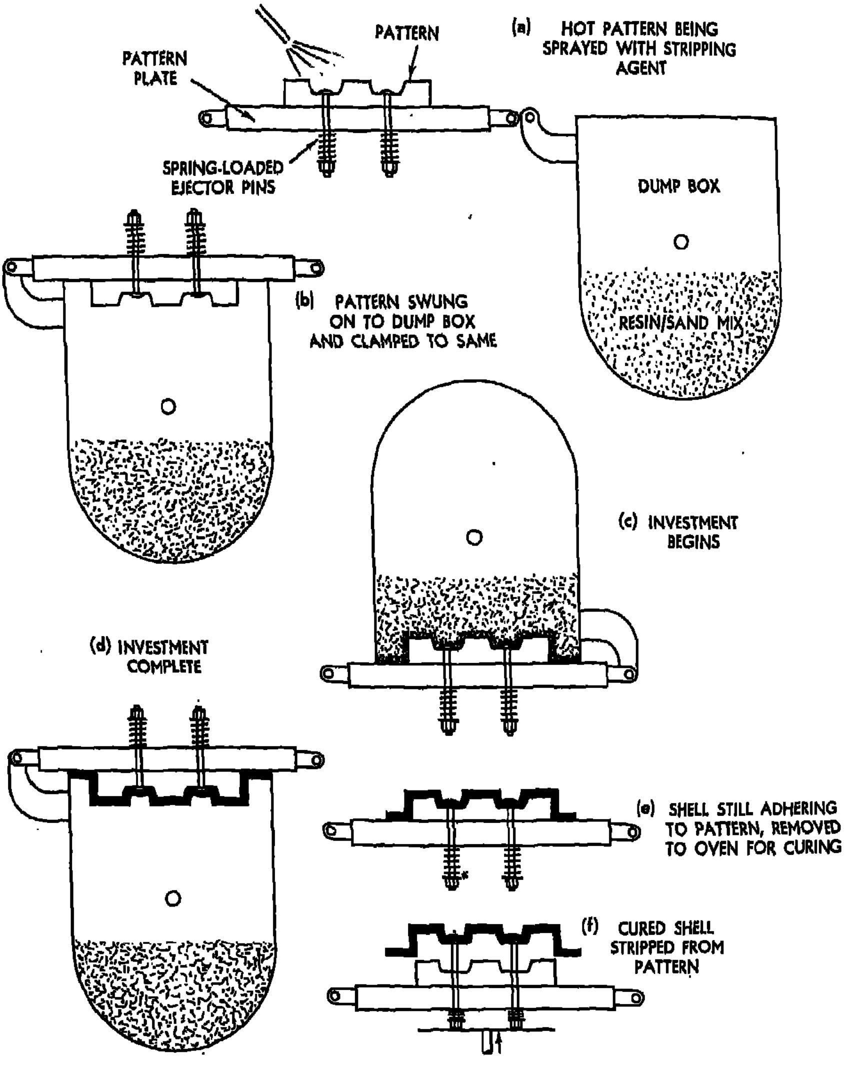

PATTERN
(a) HOT PATTERN BEING SPRAYED WITH STRIPPING AGENT
PATTERN PLATE
SPRING-LOADED EJECTOR PINS
DUMP BOX
RESIN/SAND MIX
(b) PATTERN SWUNG ON TO DUMP BOX AND CLAMPED TO SAME
(c) INVESTMENT BEGINS
(d) INVESTMENT COMPLETE
(e) SHELL STILL ADHERING TO PATTERN, REMOVED TO OVEN FOR CURING
(f) CURED SHELL STRIPPED FROM PATTERN

FIG. 11.3. *Stages in shell making.*

superior to that found on castings moulded by conventional methods.

Except in the case of large castings, say 40 lb. and upwards, it is not normally found necessary to support the shell in any way. The bond remains intact long enough for the skin of the casting to freeze and so the escape of liquid metal is prevented. Heavier castings may necessitate some form of external support to the shell. This may consist of ramming green sand around the shell or of reinforcing the weakest areas with metal bars which are held in place by a second investment.

SHELL-MOULDING MACHINES

The shell-moulding machines at present on the market can be divided into two groups, semi-automatic and automatic, but no definite dividing line exists between them. All incorporate a dump box which holds the resin-sand mix, a means of locating the pattern plate over the dump box, provision for inverting the dump box so that the mix falls on to the hot pattern plate, a means (often a separate oven) for curing the shell after investment and a device for stripping the cured shell from the pattern plate. Fig. 11.4 shows a typical machine of the semi-automatic type. The principal difference between the two types of machine lies in the aids to production which are fitted to lessen the fatigue of the operator, and in the warning and timing devices provided in order to control accurately the investment and curing periods and their working temperatures.

Although all the machines at present on the market incorporate a dump box, alternative methods of shell-making have been proposed from time to time, notably by Dietert, who favoured blowing the shells (the so-called "D" process), and by the Ford Motor Company who have produced double-sided shells by squeezing, the shells being stacked 20 high for pouring. An American machine described recently has combined both blowing and squeezing, so bringing about closer packing of the sand grains than is possible by dumping techniques. Stronger shells are thereby produced or—a more desirable feature—a shell of the same strength as a dumped one can be obtained with a lower expenditure of resin.

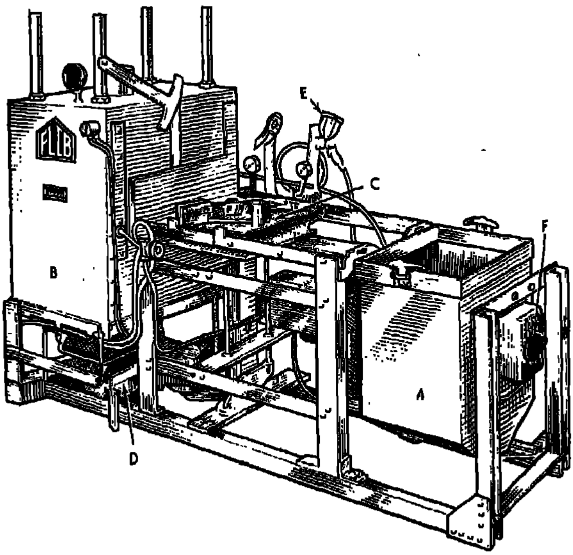


FIG. 11.4. *Shell-moulding machine.*
A—Dump box.
B—Oven.
C—Pattern plate.
D—Stripping lever.
E—Spray gun.
F—Investment timer.

TABLE 11.1. SOME SHELL-MOULDING SANDS AND TYPICAL RESIN CONTENTS

Sand	*Grading*										*Clay Content Per cent*	*Approx. A.F.S. Grading*	*Typical Resin Content Per cent*
	+ 30	+ 44	+ 60	+ 72	+ 85	+ 100	− 100	+ 150	+ 200	− 200			
Redhill F	0–5	6–12	30–40			35–45	5–15					62	5
Redhill H						5–10			65–75	15–25		140	6
Lynn SS						15–25			60–70	5–15		120	6
Chelford Fine	Trace	0·2	1·1	9·2	29·1	17·0		32·5	7·2	2·8	0·9	92	5
Erith White Silica	0·2	2·2	14·2	24·1		46·6		11·7			0·25	69	5
Levenseat No.1	0·1	1·4	10·5	20·7	29·8	13·2		18·6	5·6			74	5
Zircon Sand				1·4		8·1	+ 120 36·2	40·7	+ 240 8·8	− 240 5·0		110	2·5

TABLE 11.2. PROPERTIES OF GUNMETAL CASTINGS IN GREEN SAND AND IN SHELL MOULDS*

Mould Material	*Plate 6 in. × 3 in. × 1½ in.*						*D.T.D. Test Bar*		
	Edge			*Centre*					
	Porosity Per cent	*U.T.S. tons per sq. in.*	*Elong. Per cent (on 2 in.)*	*Porosity Per cent*	*U.T.S. tons per sq. in.*	*Elong. Per cent (on 2 in.)*	*Porosity Per cent*	*U.T.S. tons per sq. in.*	*Elong. Per cent (on 2 in.)*
Green sand	1·3	11·8	21·2	1·7	9·8	11·8	0·6	15·1	27·2
½-in. shell mould, unbacked	1·7	13·5	23·7	2·9	9·7	13·8	0·8	15·1	26·6

*Gunmetal composition: 85% copper, 5% tin, 5% zinc, 5% lead

PATTERN EQUIPMENT

The requirements of a satisfactory pattern are that it should be able to undergo repeated heating and cooling without distortion; that it should not be made up of different metals with widely different coefficients of thermal expansion; that it should be close-grained, free from porous areas and cheap; and readily worked to final dimensions yet resistant to damage during use. The best compromise between these conflicting requirements is the use of cast iron pattern plates and patterns, the former being given a stress-relieving heat-treatment before the patterns are mounted. For small or medium quantities of castings pressure-cast aluminium pattern plates have proved useful, although their susceptibility to damage virtually rules them out for longer runs. The mounting of aluminium patterns on steel or iron plates should be avoided since aluminium has a coefficient of thermal expansion twice that of steel so that in use there is a tendency for the aluminium to distort, giving trouble in stripping the shell and lowering dimensional accuracy. Good results have been obtained from the use of gunmetal or brass patterns mounted on steel or iron pattern plates.

SANDS AND RESINS

Sands. Sands for shell moulding should be clean, dry and preferably free from clay since although up to about one per cent can be tolerated, its presence weakens the shell. Shell strength is often somewhat improved by pre-firing the sand before use, although the improvement is not normally great enough to justify the expense. While sand of any grading can be used, coarse sands can be used used only at the expense of surface finish, although with the accompanying advantage that less resin is required. The grading of some common shell-moulding sands is shown in Table 11.1, together with typical resin contents. Since one of the principal claims for the process is the improved surface finish of the castings compared with conventional moulding processes, the use of a coarse sand such as Erith silica is seldom justified. It will be seen from Table 11.1 that zircon sand has been put forward as a possible moulding sand. The use of this material, which has a bulk density twice that of silica, is accompanied by excellent surface finish, improved chilling power and a saving in the use of resin, even when the difference in bulk density is taken into account. Because zircon sand costs five or six times as much as silica its use is economic only if accompanied by an efficient system of sand reclamation.

The resin in used shells is not reclaimable, but sufficient work has been carried out to show that reclamation of the sand itself, be it silica or zircon, is a practicable proposition. The resin can be burned from the sand grains in a simple reclaimer of the type shown in Fig. 11.5. This has a bottom

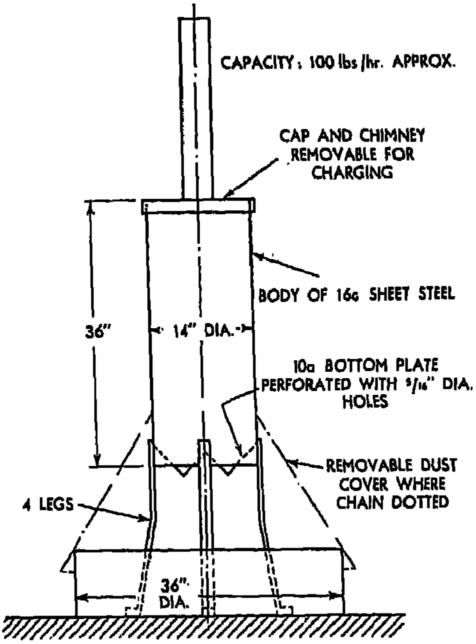

CAPACITY: 100 lbs/hr. APPROX.
CAP AND CHIMNEY REMOVABLE FOR CHARGING
BODY OF 16G SHEET STEEL
36"
14" DIA.
10G BOTTOM PLATE PERFORATED WITH 5/16" DIA. HOLES
REMOVABLE DUST COVER WHERE CHAIN DOTTED
4 LEGS
36" DIA.

FIG. 11.5. *A sand reclaimer,*

perforated to allow the sand grains to percolate through and a hole in the side for the insertion of a gas torch. Since heat is liberated by the burning of the resin, once the shells have been set alight no further application of external heat is required, and the sand needs only sieving before re-use.

Shell-moulding sands, being of fine grading, have a low permeability. This does not, however, present any problem in practice, since a shell mould is only ¼ in. to ⅜ in. thick, compared with the 3 in. and upwards of a conventional green-sand mould, and mould gases can escape readily.

Resins. Shell-moulding resins are phenol formaldehyde resins of the two-stage type. That is to say, the resin formulation is short of formaldehyde so that the mix contains about 10 per cent of an accelerator which, under the influence of heat, liberates both additional formaldehyde to make the three-dimensional linkage possible and ammonia to catalyse the reaction. In the early days of the process, urea formaldehyde resins were used to some extent, but although cheaper they break down at a lower temperature, give off an objectionable odour and need to form a larger proportion of the mix. Their use has now been discontinued.

Sand and resin are best mixed in a paddle mixer of the design customarily used for the mixing of oil-sand, but which has been modified to eliminate the central dead zone and fitted with a lid to suppress dust. A number of proprietary addition or pick-up agents are on the market which help to reduce the dusting of both sand and resin and the normal method of mixing is to add the sand first, then the addition agent and finally the powdered resin. Mixing times of 5 to 10 minutes are sufficient, and over-mixing should be avoided since this tends to generate heat, causing the mix to ball up and give trouble in subsequent investment. It is for this reason that the roller mill used for the preparation of green sand mixes is not recommended.

Precoated Sand. The use of a shell-moulding sand which by a prior operation has had the grains coated with partly cured resin has a number of advantages, particularly when the mix is to be blown as in core-making. The lower density of resin compared with sand, coupled with its finer grading, makes it difficult to avoid segregation of the two constituents when used in core blowers and precoating the sand overcomes this problem. Segregation can also occur in the dumping of shells, although here it is less of a difficulty. While there is no evidence that precoating the sand uses resin any more effectively, it may be possible, provided the precoating is efficiently carried out, to work with a lower margin of safety and so with a mix of slightly lower resin content. Against the saving thus brought about must be set the extra cost of purchasing precoated sand, or of the additional operation if the foundry itself carries out the precoating.

Two main methods of precoating are at present available. The first involves adding hot sand to the mixer, followed immediately by the powdered resin, which is partially cured by the heat and causes the mix to ball up. The mix is then cooled, preferably by adding the accelerator as a water solution, and further milling breaks up the lumps. Finally the sand is screened. The second method uses cold sand and resin which has been dissolved in a volatile solvent. The solution is added to the sand in the mixer and mixing is continued until the solvent has been largely driven off. In the later stages, the mix balls up as before and mixing must again be continued to break up the lumps.

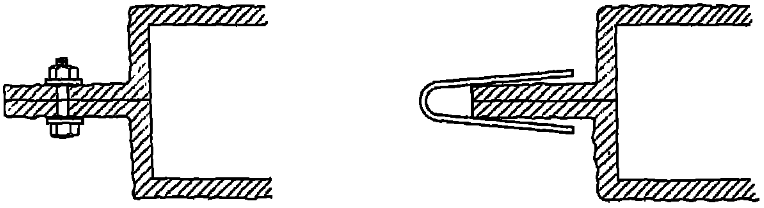
In both these methods of precoating, care must be taken to see that the breaking up of the lumps is not carried to the stage at which the partly cured resin is chipped off the sand grains. The type of mixer referred to earlier is not suitable for this work, and the roller type of mill is to be preferred. Specialized equipment for the operation is now available.

Stripping Agents. While Montan wax has formed the base of a proprietary stripping agent, most of those now in use are based on silicones. As stated earlier, such agents are applied to the pattern to ensure that the cured shell can be readily stripped from it. When precoated sands are used the use of such stripping agents can often be much reduced. New patterns should always be well treated with a silicone-base jelly before being put in to service.

Coremaking. The shell-moulding process is equally applicable to cores as to moulds, and many types of core can be made in shell form, with consequent economies in the amount of material used compared with conventional oil-sand binders. Shell cores demand a metal core box, which must be heated in the same way as a shell-moulding pattern. Cores can be dumped or blown. In the latter case, the use of a precoated sand is almost obligatory. Shell cores are light, easily inserted in the mould and readily removed from the casting. When removed from the box they are ready for immediate use, strengthening devices are eliminated or much reduced, and complicated shapes can be made without the need for core driers.

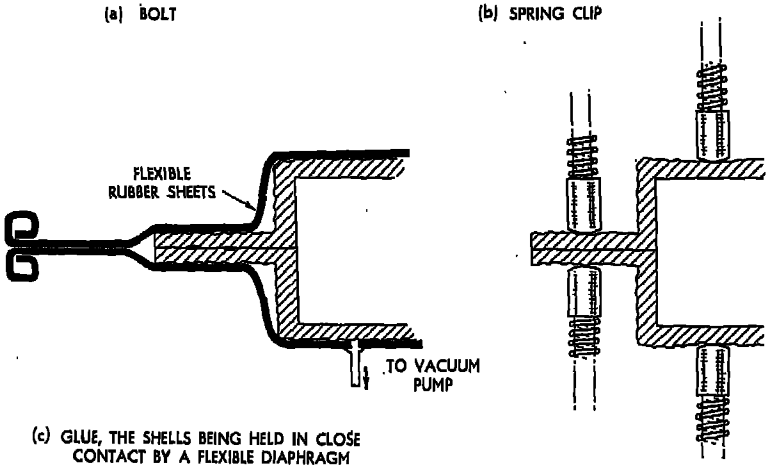
CLOSING OF SHELLS

A production rate of 30 shells per hour throughout the day is possible from the simpler types of semi-automatic machines and rates up to 40 or 50 per hour are possible from the automatic machines in which the investment and curing cycles are closely controlled. With some of the closing methods employed, it has often proved difficult to ensure that closing keeps pace with shell production. In Fig. 11.6 are shown details for overcoming this problem. Of all the methods at present available, probably the most accurate is the use of bolts. These are sited strategically on the shell, both around the edges and in the interior, although clearly no bolt can be put through the actual mould cavity. Provided the greater part of the shell



(a) BOLT

(b) SPRING CLIP



(c) GLUE, THE SHELLS BEING HELD IN CLOSE CONTACT BY A FLEXIBLE DIAPHRAGM UNTIL THE GLUE HAS HARDENED

(d) SPRING-LOADED PINS

Fig. 11.6. *Four methods of closing shells.*

does not consist of mould cavity, dimensional inaccuracies across the joint line are in this way kept to a minimum; but the method is very time-consuming, the nuts and bolts need recovering after casting and there is a steady wastage through metal spillage.

Clipping round the outside of the shell is another method sometimes practised. The method leaves scope for distortion in the centre of the shell and on this account it is often supplemented by bolting at such points. Other methods include holding the two shells together by spring-loaded pins pneumatically or mechanically actuated. This method, while speedy, suffers from a lack of flexibility in that the pins making contact with the shell must have their centres changed with each job. Nevertheless, for long runs the method is often the best available.

Perhaps the most flexible method available to the ordinary foundry is gluing, and equipment is now on the market in which, after a urea or phenol formaldehyde glue has been applied to the hot surface of one of the shells, the two shells are held together under pressure until the glue has hardened. When this pressure is applied, by sandwiching the shells between two flexible rubber sheets and evacuating the space between them, closing is speedy and has the added advantage that the equipment can handle a wide variety of shell shapes and sizes without modification. A convenient method of applying glue to the face of the shell is by squeezing it from a polythene bottle. A recent development is to feed from a dispenser solid pellets of phenol formaldehyde resin glue on to the hot shell, followed by the application of pressure as before. In all cases care must be taken to prevent glue falling into the mould cavity, and also against applying so much glue that the shell faces are not in contact.

DIMENSIONAL TOLERANCES

It is necessary to distinguish between close dimensional tolerances and high dimensional accuracy since the cost of the resultant castings can be markedly affected if this is not done. The dimensional accuracy of a casting is determined by the care with which the pattern is constructed and the extent to which the amount of contraction can be accurately predicted. The dimensional tolerance which must be accepted in any batch of castings is the variation about an average size which will occur due to the variables inherent in the process. Such variables in shell moulding include the degree of curing, the mould material used, the care taken in closing and the method of running and gating employed.

When dimensional accuracy must be considered in terms of thousandths of an inch the construction of patterns to such limits is bound to be costly. The design will play a large part in the amount of contraction which occurs so that should a dimension of, say, 10 in. be required, considerable trial-and-error work may be necessary in the foundry if a batch of castings is to average this. In many instances, though, such accuracy is not needed; instead, it is of importance to the user merely that a close dimensional tolerance should be held about a dimension nominally 10 in. but which may in practice be 10·015 in. If such an approach can be made, pattern costs need not be excessive, normal contraction allowances can be made and it only remains to decide what dimensional tolerance is practicable. Although a number of claims have been made in this connexion, little work has been published showing the dimensional tolerance possible on a batch of castings of any size. A good working rule is to regard a tolerance of ± 0·005 in. per inch on a dimension up to 3 in. as practicable, provided that this is not measured across a joint line. For dimensions larger than 3 in., closer tolerances are possible; when a joint line is involved the figure quoted may need to be doubled or trebled, depending to some extent on the method of closing employed.

MECHANICAL PROPERTIES OF SHELL-MOULDED CASTINGS

The cooling rates of castings made in shell moulds are slower, other things being equal, than those made in green sand, although a considerable part of this difference takes place after the casting has solidified and is therefore of little practical importance. It is usual to find that in any given alloy the slower the cooling rate the larger the grain size; since large grain sizes are often associated with poor mechanical properties it was reasonable to suspect that shell-moulded castings might be at a disadvantage in this respect. Little comparative information on mechanical properties has been published, but it will be seen from Table 11.2 that gunmetal castings made in shell moulds are not inferior to those made in green sand. American work on certain magnesium alloys has shown much the same trend, although there is some evidence that where heat-treatable aluminium or magnesium alloys are concerned, shell-moulded castings may show a slight falling off in properties.

The principal advantages of the shell-moulding process may be summarized as follows:

(*a*) Closer dimensional tolerances than are possible with conventional sand moulding.

(*b*) Greater production from a given floor space.

(*c*) Elimination of or a reduction in machining allowances because of the closer dimensional tolerances which can be worked to.

(*d*) A shell mould contains only about 10 per cent of the weight of sand of a green-sand mould and no box parts are needed.

(*e*) The process lends itself to intensive mechanization and the employment of female labour raises no major difficulties.

(*f*) Casting quality is more consistent.

The major disadvantages are:

(*a*) Casting for casting, the process is more expensive than conventional moulding methods.

(*b*) Since heat is needed to soften the resin, metal patterns must be used, with a correspondingly high pattern cost. The process is therefore unsuited to small quantities.

(*c*) Since the silica sand used is fine and dry, adequate dust-extraction equipment must be installed to avoid any danger from silicosis.

These points will now be elaborated in more detail.

The good surface finish and close dimensional tolerances of shell-moulded castings are obtained by the expenditure of considerable sums on synthetic resins. Such resin costs outweigh in the vast majority of cases the savings which can be made in direct labour, and by economy in floor space. Improved soundness of castings, freedom from blowholes, etc., are difficult to assess in general terms and must necessarily be something which a foundry can measure only after a shell-moulding plant has been installed and has been working for a considerable period. Without exception a shell-moulded casting made in the same way—i.e. with the same pattern, core box, machining allowances and gating system as the green-sand casting it replaces—is more costly. (Comparisons which have been made in the past between the cost of a casting made from shell-moulding pattern equipment and one moulded in green sand from a loose wooden pattern are, of course, invalid because like is not being compared with like.)

It follows, therefore, that if an economic case is to be made for the supplanting of green-sand moulding by shell moulding, the castings produced by the latter process must be so designed that the improved surface finish and dimensional tolerances characteristic of shell moulding can be exploited to bring about significant reductions in post-foundry operations such as machining and polishing. Ideally, a machining operation should be eliminated; there is little to be gained in most cases from reducing the machining allowance since it costs virtually as much to remove $\frac{1}{32}$ in. as $\frac{1}{8}$ in. The saving in the weight of the metal used represented by such a reduction in machining allowance is, by itself, usually too small to tip the economic advantage in favour of shell moulding. The economics of coremaking are considerably more favourable, since a shell-moulding mix costs only about three or four times that of an oil-sand mix. The core can often be made hollow, so that the reduction in the material used goes a long way to compensate for the increased price. In addition, shell cores are ready for use immediately they leave the core box, the handling inseparable from the bulk-drying of oil-sand cores is eliminated, and no expenditure on core driers has to be incurred.

THE CARBON DIOXIDE PROCESS

ALTHOUGH the carbon dioxide process was the subject of a British patent as far back as 1899, it was only in 1955 that it came into general use in this country, being reintroduced from the Continent. It has made rapid strides since then and seems destined to occupy a prominent place in the means of production at the disposal of the founder, not least because of its wide applicability.

Clean, dry silica sand is mixed with a binder based on a solution of sodium silicate, and carbon dioxide gas is passed through the rammed mass for a period normally measured in seconds. The reaction which takes place can be broadly represented by the following equation:

$$\underset{\text{Sodium silicate}}{Na_2O.SiO_2.\,x\,H_2O} + \underset{\substack{\text{carbon}\\ \text{dioxide}}}{CO_2} \rightarrow \underset{\substack{\text{sodium}\\ \text{carbonate}}}{Na_2CO_3} + \underset{\text{silica gel}}{SiO_2.\,x\,H_2O}$$

The sand grains are bound together by the silica gel and the core or mould is then hard enough to be handled. Provided that gassing has been correctly carried out, it will harden still further if allowed to stand in the atmosphere. Such additional hardening may be desirable, and can be accelerated by a short stoving treatment at 200 deg. C.; but in most cases the core or mould is sufficiently strong immediately after gassing and can be used for the production of castings without the need for any further treatment except, perhaps, the application of a dressing. This elimination of stoving is one of the principal attractions of the process, but it is by no means the only one. Nor is the process without disadvantages, however.

The process is used for the production of large moulds from wooden patterns, replacing dry-sand work; of small repetition castings to a high standard of surface finish and close dimensional tolerance, so acting as a substitute for shell moulding; of cores for the jobbing foundry using wooden core boxes; and of repetition small cores either by hand methods or, preferably, by blowing or shooting. Some modification to the basic mix may be necessary for a particular application. For example, the construction of the pattern or core box may be such that gassing cannot be carried out when the pattern is in the mould or the core in the box. In such a case, an addition is made to the mix so that its green strength is raised sufficiently to enable the pattern or core box to be removed before gassing.

The process is suitable for all the common casting alloys and it will be realized from what has been said that a very wide range of casting size is possible with the process. Figs. 11.7 and 11.8 show some examples of the castings which have been made. At the present time the principal applications lie in the manufacture of moulds and cores for steel, iron and

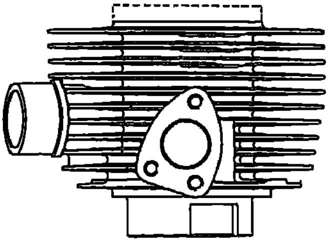
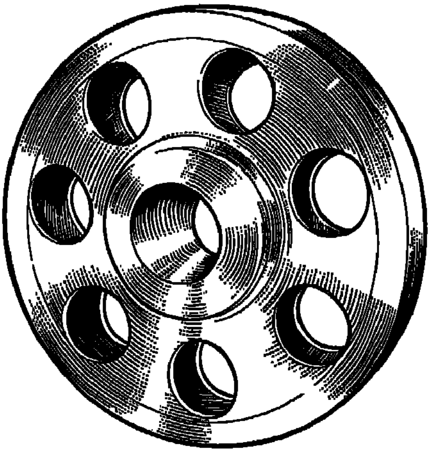


FIG. 11.7. *Cast iron cylinder for the Vespa motor scooter, made by the* CO_2 *process.*



(Right) FIG. 11.8. *A 6-ton steel casting also made by the process.*

copper alloy castings, and of the sand cores used in large quantities in the production of aluminium alloy castings by the gravity-die process.

CARBON DIOXIDE MIXES

Most of the common foundry sands have proved satisfactory and some typical mixes are shown in Table 11.3. The sand used should be clean and preferably dry and free from clay. While the last two conditions are not essential, failure to observe them leads to a reduction in shelf life and a lower gassed strength respectively. Similarly, while certain clay additions are sometimes made if the mix is required to have a green strength higher than the normal 1 lb. per sq. in., the use of clay-bearing sands should be avoided where possible, and the amount of clay present kept to a minimum in any case. The reduction in gassed strength is largely dependent on the type of clay used; active clays like bentonite have a particularly marked effect while ball clays have much less influence.

When the pattern must be withdrawn before the mould is gassed, the use of a mix with some green strength becomes obligatory. The use of ball clay can raise the green strength to around 3 lb. per sq. in. and various proprietary additives are on the market which have the same effect. Other additives made to the basic mix are designed to improve surface finish. Prominent amongst these are pelleted pitch, wood-flour and graphite. Such additions rarely exceed 1 per cent. They also aid collapsibility, to which further reference is made later.

The paddle-type mixer used for oil-sand is most suitable for this process. The order of addition should be sand, carbonaceous addition

TABLE 11.3
SOME TYPICAL CO_2 PROCESS MIXES

Sand	*Binder (Per cent)*	*Other Additions*	*Application*
Congleton	3½	1 per cent pitch or 2 per cent coaldust	Moulds and cores for steel, cast iron and copper alloys
Congleton	4	10 per cent natural sand	Moulds for steel, cast iron and copper alloys when gassing is to be done after withdrawal of the pattern
Equal parts of Southport and Redhill H	5	1 per cent pitch	For copper alloy moulds. No dressing required
Erith	3	1 per cent wood-flour	Moulds for aluminium alloys
Erith	3½	1 per cent wood-flour	Cores for aluminium alloys

and binder, and mixing should be complete within 4 to 5 minutes. Overmixing should be avoided, since this raises the temperature, reduces the water content and may lead to friability after gassing.

Although not strictly a part of the mix, it will be convenient to deal with dressings at this point. With cast iron and the copper alloys it is normal practice to apply a dressing to the core or mould in order to give a satisfactory surface finish. With steel (particularly when the section thickness is large) and with aluminium alloys, dressings are seldom needed. Even with cast iron and copper alloys it is often possible to dispense with their use if a finer sand, exceeding 100 A.F.S., is used. While such a sand lowers the permeability, CO_2 process mixes tend, as will be shown later, to have a rather higher permeability than when the same sand is bonded with oil. There would, therefore, seem to be considerable scope for the use of finer sands and a consequent reduction in the use of dressings. When a dressing must be used, the choice lies between one with a water and one with a spirit base. The latter, although more expensive, is to be preferred. The application of a water-base dressing tends to roughen the core or mould surface, but the main objection is that the core or mould must subsequently be stoved or at least thoroughly skin-dried—clearly an unwelcome course when one of the chief claims of the process is that stoving is eliminated. A spirit-base dressing merely needs igniting and no stoving is necessary.

CO_2 mixes tend to dry out on the bench, but this can be quite simply overcome by covering the unused mix with a damp sack and seeing that excessive quantities are not mixed at any one time. The shelf life of gassed cores and moulds is often variable. Some foundries claim that shelf lives of several weeks are practicable and that cores and moulds can be left standing for several days before casting without any danger of "striking back"; whereas others have found that after a day or two the quality begins to deteriorate. There is little doubt that lengthy standing should be avoided (although, as stated earlier, a gassed core hardens further if allowed to stand in the atmosphere after gassing) and it seems likely that the wide variation in behaviour is associated with the amount of gas which has been used. If excessive amounts of gas are passed through a core (and figures have been quoted which indicate that gassing is sufficiently complete if 0·2 per cent of gas by weight of mix is used), shelf life is likely to fall off quite considerably. Similar results are found if wet sand is used, and lack of adequate facilities for drying sand may also be a cause of the poor shelf life sometimes experienced. The flowability of CO_2 process mixes is good and eminently suitable for use in core blowers and core shooters. Very large quantities of cores are currently being produced by these means.

The green compression strength of the standard CO_2 mix is about 1 lb. per sq. in., but this can be increased to about 3 lb. per sq. in. by the addition of a suitable additive such as ball clay, sulphite lye or natural clay bonded sand. The compression strength of gassed CO_2 compacts rarely if ever exceeds 600 lb. per sq. in. and figures of 200 to 400 lb. per sq. in., depending upon the standing time after gassing, are much more common. While these compression strengths are adequate for most purposes, they must be compared with figures of 1,200 lb. per sq. in., or more for oil-sand and shell-moulding mixes. Cores possessing thin projections and narrow necks may be difficult to handle when made by the CO_2 process, and it is not always either practicable or desirable to remedy this by an increase in the number of strengthening devices.

The gas evolution from CO_2-process cores is about one-half that from comparable oil-sand cores. This figure may be somewhat increased if carbonaceous additions such as pitch are made but is still well below that of oil-sand, although in the early stages the rate of gas evolution may be slightly greater. Details are shown in Fig. 11.9. The permeability of a given sand tends to be greater when sodium silicate replaces oil as a binder. For example, Congleton sand showed a permeability of 135 A.F.S.

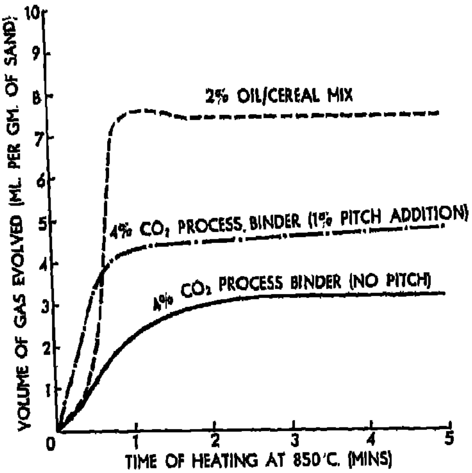


FIG. 11.9. *Comparison of the evolution of gas from the CO_2 process and from oil-sand mixes.*

when bonded with oil and of 172 A.F.S. with a CO_2-process binder. As stated earlier, this significant improvement in permeability, taken in conjunction with the much smaller amount of gas evolved, makes it possible to use finer sands for coremaking without the risk of blown castings.

Collapsibility, i.e., the facility with which the core can be removed from the casting, has on occasions given rise to some difficulties, and although these have in many cases been overcome, this property represents one of the least satisfactory features of the process. The first essential is to work with the smallest addition of binder which will give a satisfactory gassed strength. The second is to make an addition of a carbonaceous material (pelleted pitch being the most common) which will char at the temperature of casting and so weaken the bond. Fig. 11.10 shows what happens when sand compacts bonded with sodium silicate are heated to various temperatures for a fixed time and then tested under compression. It will be seen that the compacts heated to 200 deg. C. display a very large increase in compression strength, while the strength of compacts heated to higher temperatures falls off progressively to a low value at about 600 deg. C. After this a further rise occurs. Copper alloys and cast iron have casting temperatures of 900 to 1,400 deg. C., and the addition of pitch is designed to counteract the rise in strength found at these temperatures. With aluminium alloys which have casting temperatures in the 600 to 700 deg. C. range CO_2-process cores have good collapsibility, as would be predicted from Fig. 11.10, and additives are not required.

Even when all these ameliorative measures have been taken, collapsibility still presents a problem on occasions, and it can often be overcome by making the core hollow, i.e., in shell form. It is often most convenient to do this by inserting a perforated mandrel in the core and gassing through this. The hollow core can then be removed from the core box ready for casting. There is a clear economic advantage in making cores hollow, apart from any other consideration, and whereas such a course would often be impossible with an oil-sand core because of its low green strength, no corresponding problem arises with CO_2-process cores, since in most cases these need not leave the core box until they have been gassed.

CO_2 GAS AND ITS APPLICATION

Carbon dioxide gas can be supplied in cylinders, in the solid state and, when consumption is large, in bulk liquid form. The end product is the same in each case and the means of supply selected by any particular foundry is a matter of economics and convenience. It is not worth considering the use of solid CO_2 unless the gas consumption is more than 10 tons per year and bulk liquid demands the consumption of 40 tons per year or more. Gas in the cylinder must have its pressure reduced by means of a reducing valve if wastage of gas in the foundry is not to occur. Such a reduction in pressure is accompanied by a fall in temperature in the case of all gases, but the effect is more severe with carbon dioxide than with most, being about 1 deg. C. for each atmosphere difference in pressure across the exit nozzle. If, therefore, the drop from cylinder pressure to working pressure is allowed to take place in one stage, the fall in temperature is sufficiently great for solid carbon dioxide to form in the gassing tube, so that the flow of gas to the core or mould is reduced or interrupted completely. To overcome this, the pressure should be allowed to fall in stages and if consumption is at a high rate, some simple form of heating should also be incorporated between these stages. A number of suitable reduction valves incorporating these measures are on the market. Standing a cylinder in 6 in. to 8 in. of water also helps to maintain the temperature of the gas.

In the early days of the process, the amount of gas that was used was, economic considerations apart, regarded as unimportant. The position is different now and the need to avoid excessive over-gassing is stressed. Sodium silicate-base binders nevertheless possess a reasonable

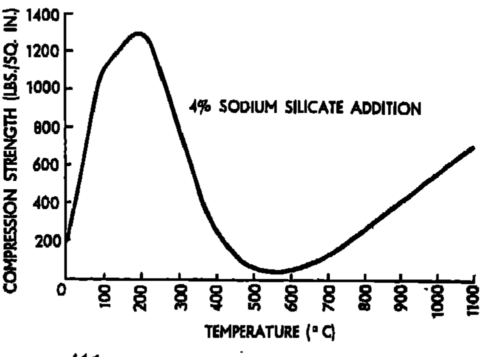


FIG. 11.10. *Effect on strength of heating gassed compacts for 10 minutes, at various temperatures.*

TABLE 11.4

CHEMICAL ANALYSIS OF CO_2 PROCESS CORES GASSED FOR VARYING PERIODS OF TIME. (*AFTER ATTERTON*)

	GASSING TIME (SEC.)						
	0	15	30	45	60	180	360
CO_2 content, per cent	0·01	0·350	0·338	0·357	0·388	0·450	0·412*
Na_2CO_3, per cent	—	0·640	0·660	0·615	0·570	0·490	0·380
$NaHCO_3$, per cent	—	0·050	0·100	0·170	0·220	0·350	0·390
Per cent binder reacted	—	57	62	62	65	65	65

* Per cent binder low in sand.

latitude in this respect. Table 11.4 shows the effect of passing gas through a rammed compact for various times. It will be seen that as the gassing time increases there is a rapid reaction with the binder until 65 per cent has been converted, largely to sodium carbonate. Beyond this point, passing further gas does not convert any of the remaining binder but the proportion of sodium bicarbonate present increases markedly. Analysis of the white powder found on the surface of cores and moulds which have been gassed for long periods has shown this to consist of sodium bicarbonate. Such overlong gassing times result in cores and moulds with a friable surface and possessing a poor shelf life. Whether the sodium bicarbonate is a symptom or a cause of such a falling-off in properties is at present uncertain. The best practice is to under-gas rather than over-gas and to allow the core to harden further in the atmosphere. Such a course is the most economical in gas consumption and gives strong cores with a good shelf life.

Some of the simple methods of gas application are shown in Fig. 11.11. It is not always realized that to talk in terms of pressure of gas and the time of its application is no measure of the amount of gas which has been used; and as emphasized above it is highly desirable that gas should not be used to excess. The methods shown in Fig. 11.11 all aim to pass gas through the rammed mix, whereas the method shown in Fig. 11.12 aims, by evacuation of the air in the pores of the rammed mass, to replace this with carbon dioxide which will quickly react with the binder present. Undoubtedly, the latter method represents the ideal to aim at although it may not be practicable for small quantities.

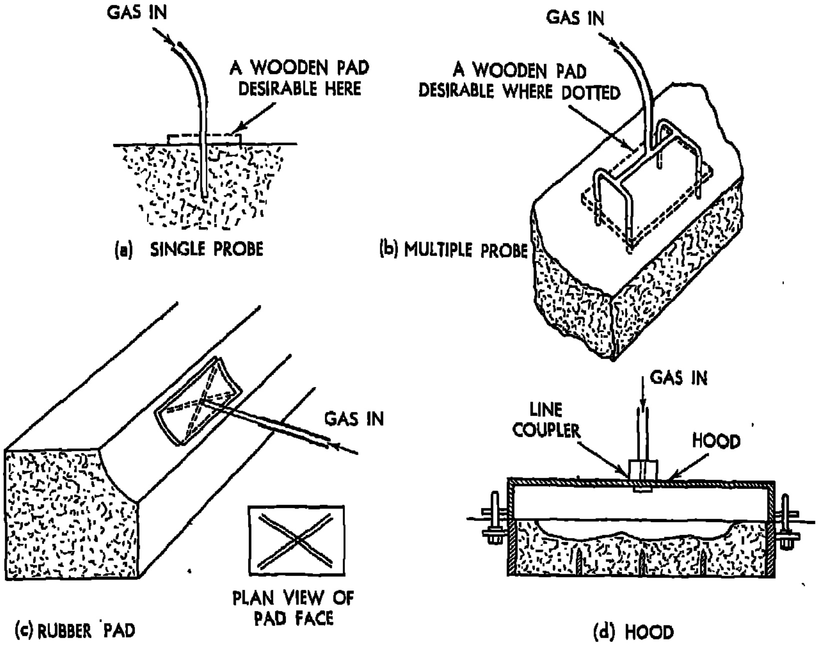


FIG. 11.11. *Four simple methods of gas application.*

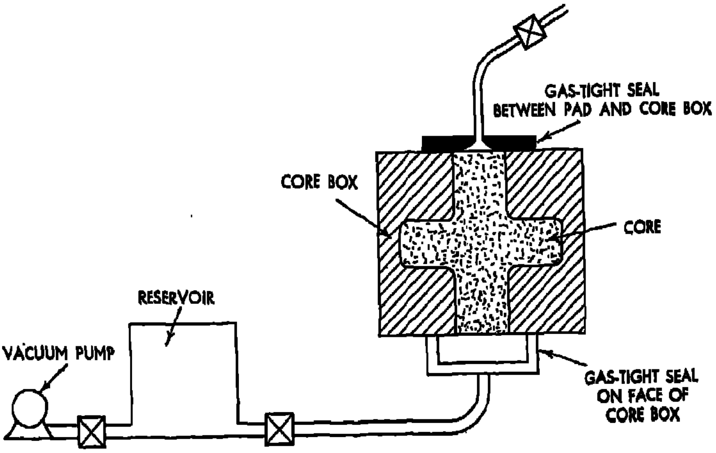

GAS-TIGHT SEAL BETWEEN PAD AND CORE BOX
CORE BOX
CORE
RESERVOIR
VACUUM PUMP
GAS-TIGHT SEAL ON FACE OF CORE BOX

FIG. 11.12. *Another method of gas application.*

Whatever the exact details of gassing may be, it is important to realize that gassing can be effective only if the air present in the pores of the rammed mass is replaced by gas. Provision must therefore be made for the escape of this air, together with precautions to prevent gas from escaping along the easiest path, leaving certain regions of the core or mould ungassed. When cores are being blown, the vents built into the core box to ensure that air pockets are not created during blowing may not be sited to give the optimum gassing conditions.

PATTERNS AND CORE BOXES

Both wood and metal patterns can be used with CO_2-process mixes, although with the former it will be found that the normal pattern varnishes are attacked by the alkaline binder, causing sticking. Good results can be obtained by using an alkaline-resistant cellulose varnish or a silicone-base lacquer. Although both are expensive, their use is well worth while. While existing pattern equipment is often quite suitable for use with the process, it must be borne in mind that since gassing is normally carried out before the removal of the pattern or core box any roughness or undercuts will cause serious sticking because of the inability of the mould or core to yield. (The use of a mix with some green strength may, as stated earlier, enable gassing to be carried out after the withdrawal of the pattern or core box, but such a course is not usually desirable or always practicable.) Inadequate taper may give the same trouble and tapers should in all cases be on the generous side. Where this is not possible, patterns and core boxes should be constructed on the "breakdown" principle, i.e. they should be constructed in sections which can be taken apart after gassing. Because of their paraffin content, liquid parting agents are not recommended and parting powder is to be preferred. Rubbing a core box with graphite often aids withdrawal.

DIMENSIONAL TOLERANCES

In distinction to the shell-moulding process, it is not possible to be so precise about the dimensional tolerances possible with the CO_2 process because of the widely differing applications which are possible with it. Where it is being used as a substitute for dry-sand moulding, the dimensional tolerances possible should be at least as good as those obtainable with dry sand. Where it is used as a substitute for shell moulding, the tolerances should approach those obtainable with that process, provided a fine sand is used. If a mix is made using a coarse sand, a dressing must be used, and this will introduce inaccuracies and give an inferior result. Where the CO_2 process is being used to supplant oil-sand cores, closer tolerances are certainly possible since no sagging will occur in the green state. It will be appreciated from what has been said above that close tolerances can only be held if gassing is carried out before the pattern or core box is withdrawn.

ADVANTAGES AND DISADVANTAGES

Many aspects of core and mould production have been touched on in the foregoing, but it will be convenient to summarize here what has been said so far as it affects such production. The principal advantages of the process for coremaking are that the mix is equally suitable both for hand coremaking and for coreblowing. Cores can often be made hollow, with a consequent saving in binder. Where, as is often the case, core irons and other strengthening devices are used to strengthen the green core, these can be eliminated or at least reduced in complexity. Because the core need not leave its box in the green state no expenditure need be incurred on core driers. Damaged cores are easily patched, and chills can be incorporated without fear of the core sagging. But the principal attraction of the process is undoubtedly the fact that stoving can be avoided, with all the savings in time, stove capacity, floor space and fuel which that entails.

Many of the advantages listed for cores apply to moulds. The most common practice is to use only a facing of CO_2 mix, 2 in.–3 in. thick, against the face of the pattern. This economizes in binder. The primary application of the CO_2 process for moulding is as a substitute for dry-sand moulding, the elimination of stoving being the principal attraction, although the ability to use a less skilled grade of labour has been the prime reason for its adoption in certain instances. The disadvantage of the process at the present time is the lack of any cheap or proven method for the recovery of the spent sand which, apart from use as blocks in the centre of large cores, must be discarded after use. This is one reason why only a facing of CO_2 mix is used for moulding. The lack of such a method of reclamation undoubtedly is hindering the adoption of the process on the moulding side at the present time, but presents no problem on the coremaking side, where the reclamation of oil-sand is not normally practised.

One fear which has been expressed concerning the process seems to be groundless. The build-up of sodium compounds in a moulding sand has been frowned on in the past because it was thought this would have an adverse effect upon its refractoriness; but no difficulties have been experienced in this respect by foundries which have worked the process for many months. The only noticeable effect of this dilution of the normal clay-bonded sand by CO_2 mix has been a slight fall in green strength, which can be quite simply corrected by an addition of natural sand or of a clay such as bentonite.

Chapter 12

FETTLING PRACTICE

WHATEVER type of mould is used, castings will require cleaning and trimming before they can be passed on for machining, or other operations. The amount of work to be done will vary, not only with the sizes of castings and types of alloys used, but also with the care and degree of accuracy given to the production of the mould and core. The noise and dusty atmosphere usually associated with fettling shops are apt to give the casual observer an impression that here is a phase in production which requires little or no skill, and is just another form of scavenging. This is entirely wrong, and it is important to appreciate that the saleability of a foundry's products can be either definitely enhanced or entirely marred by the finish produced by the fettler.

If we consider castings made in sand moulds, as distinct from die castings, the work of the fettler should be limited to removing runners and risers and cleaning off any adhering sand. Though it is true that such ideal conditions exist in many foundries making repetition light castings such as those for switchgear, when heavier and more intricate castings are involved, a great deal more work is necessary to remove cores, flash metal at joints, and surface imperfections. It will be remembered, from previous chapters, the influence the melting point of alloys has on the properties of sand, and that, as temperatures rise progressively from white metal alloys to cast steel, the refractoriness of the mould materials must be improved. Nevertheless, it can be said that, generally, the higher the metal melting point the greater the surface roughness of the castings. Of course, rate of cooling, as influenced by metal thickness, will be an equally important contributory cause. From these remarks it will be obvious that the heavier castings in grey and malleable cast iron and cast steel call for the most work in fettling. As fettling is not a precision operation in the same sense as machining, the main function of the equipment of this department is speed in removing all unnecessary metal and the production of a reasonably smooth finish.

REMOVAL OF SAND

The first job, after a casting arrives at the fettling department, is to remove any sand which is adhering from the mould and cores. The way this is done will depend on the size and intricacy of the casting. If the design is fairly simple, rapping with a hammer, followed by wire-brushing or shot

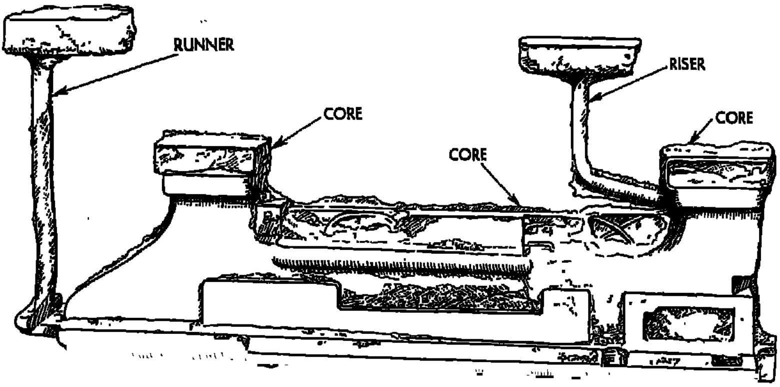


FIG. 12.1. *A large casting after removal from the mould and before fettling.*

blasting, will usually suffice. As the design becomes more intricate the operation takes longer, especially to remove cores and their wire or grid reinforcements. It will be remembered that, although a wide range of castings can be made in green sand moulds, cores are more usually dried; and dried sand, especially if it is artificially bonded, is not an easy material to break up. At the same time dry sand moulds and cores usually strip well, and once the sand is removed the fettler has little to do to the skin of the casting.

If Figs. 12.1 and 12.2 are studied, it will be seen how laborious this

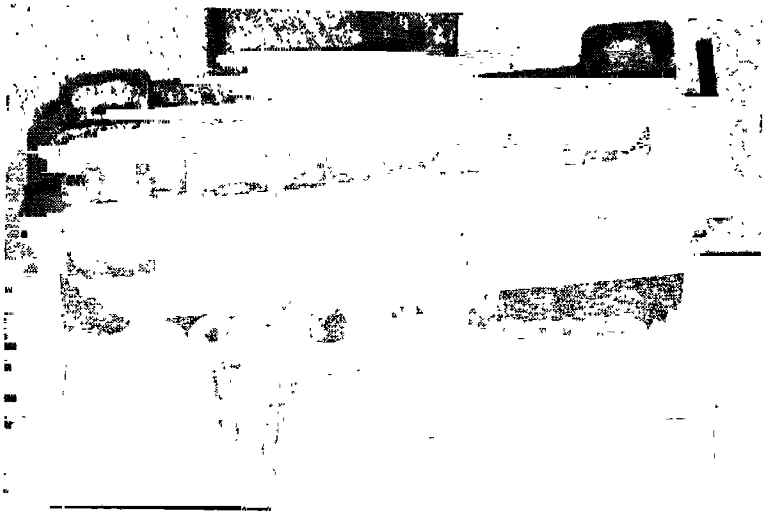


FIG. 12.2. *Heavy castings immediately after removal from moulding boxes.*

cleaning becomes on heavy, intricate castings, especially if only picks and bars are employed. Pneumatic picks are used to some extent, but generally the mechanical aid they offer is offset by their weight, and considerable dust is created by their exhausts. The latter disadvantage can, however, be overcome by using water sprays in conjunction with the tool.

WET PROCESS OF CLEANING

The idea of cleaning castings by the wet process has always been attractive, largely because it seemed to offer promise of elimination of the dust problem. The operation has been proved so completely successful as to be accepted as a standard method of cleaning. Actually, one system goes very much further than merely cleaning the castings, in that it also cleans the sand and delivers it graded within the grain sizes required, and, in addition, at least equal to new unbonded silica sand. The early attempts in cleaning wet were mainly on medium to large castings, and concerned primarily with removal of cores. The G.E. Company at Erie, Penn., U.S.A., put in a casting-washing plant before 1920, and this and similar plants were adaptations of hydraulic mining. Water at a pressure of 300 to 400 lb. was discharged from a nozzle mounted on a fixed support at the rate of several hundred gallons per minute. This method removed the cores that were relatively soft and easily accessible, but there were serious limitations.

There have been various stages in the development of this wet process until we arrive at that offered today which does so much more than merely washing out the cores. One such plant embodies a gun which is easily handled by one man. This projects a fine stream of water and sand against the casting at a pressure of 1,700 lb. with a velocity in excess of 3 miles a minute. The quantity of water used is about 25 gal. per minute, carrying with it up to 70 lb. of sand per minute. Heavier equipment is available which includes a gun working with water at 2,000 lb. pressure and delivering 50 gal. per minute. This gun is operated mechanically from outside the chamber; it is mounted in a carriage which can be moved the entire length of the room and vertically as may be required. The gun swivels in the carriage in a cone of more than 90 deg. All the motions are controlled by two levers outside the room actuated hydraulically and electrically. No special abrasive is required, as the sand cleaned from the castings is quite suitable. It is claimed that this system cleans the surfaces of the casting rapidly and thoroughly, and that the stream of water and sand mines out even the hardest cores in less time than any other known method (Fig. 12.4).

In connection with the problem of dust removal, research has shown that the wetting out of dust particles requires a water supply at high velocity. In the one plant referred to, in which the water is at a pressure of 1,700 lb. and a velocity of 3 miles a minute, it is claimed that this stream

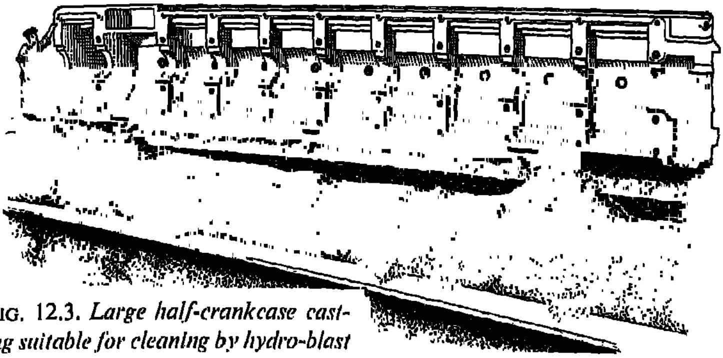


FIG. 12.3. *Large half-crankcase casting suitable for cleaning by hydro-blast equipment.*

instantly wets out every particle of dust at the source, which is the surface of the casting, or within the core. By virtue of its high velocity, this stream of water also removes the dust created by other foundry operations which is otherwise left suspended in the air.

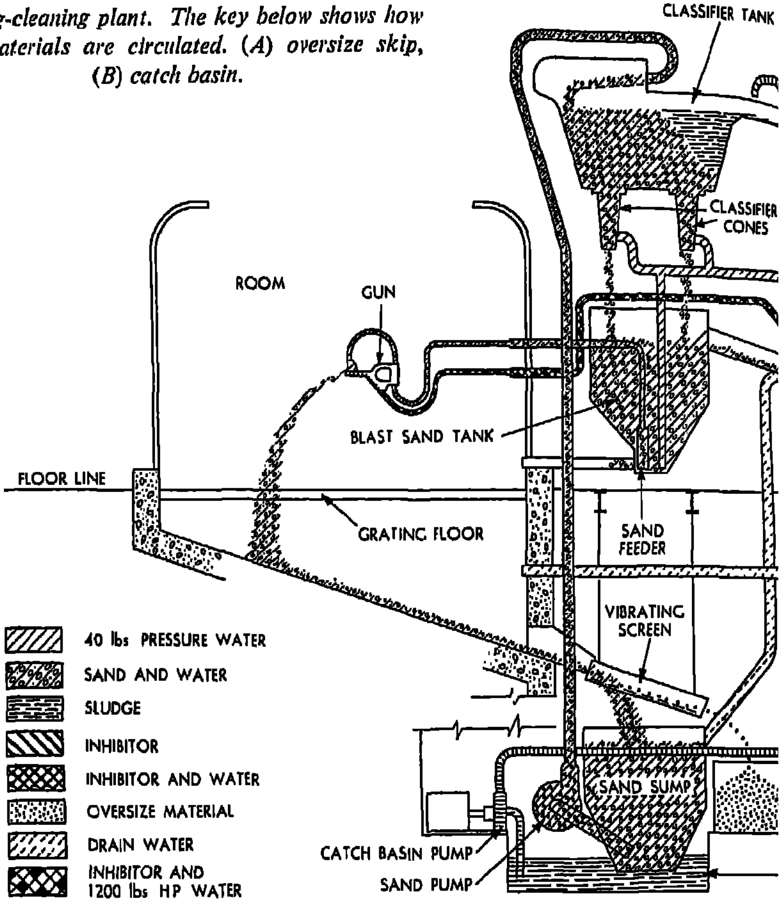
Naturally, such a complete plant as this means large capital expenditure, and the question arises, when can a plant be profitably introduced? The answer depends upon the class of work, local conditions, sand costs, etc. The plants are supplied complete with sand recovery and classification, or with sand recovery only. The large plants with outside operation of the gun, when complete with sand classification, involve a high capital expenditure and so are mainly of interest to the larger foundries, but simplified plants with interior 25-gallon guns and no sand classification cost very much less. It is claimed that if the output of a foundry is in excess of 10 tons per day, and the castings are of sufficient intricacy, such as that shown in Fig. 12.3, a plant could be made to pay for itself in two years.

SHOT BLASTING

As the name implies, this consists of projecting, at high velocity, a stream of fine abrasive against the casting to produce a thorough cleaning of the surface. Originally, the abrasive used was sand of fairly large grain size and the process was known as sand blasting. The disadvantage of this process is that sand, which is silica in granular form, is comparatively soft and on impact with a hard metallic surface rapidly breaks down in size, thus reducing the life of the abrasive. A second and more serious disadvantage is that when silica dust is persistently inhaled, it sets up irritation of the lungs and may develop into the tubercular disease, silicosis. Consequently, under a Factory Act, the use of sand is restricted to the treatment of small ornamental work and glass frosting.

The use of round, or angular, chilled iron shot in place of sand was,

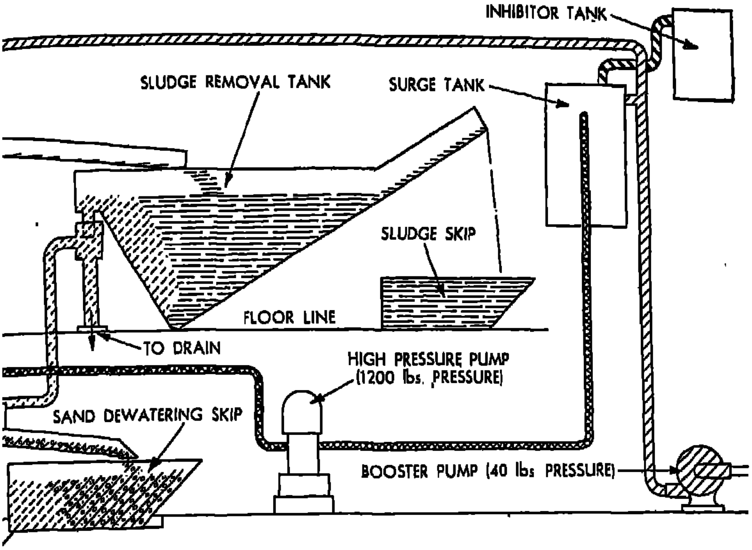
FIG. 12.4. *General arrangement of hydraulic casting-cleaning plant. The key below shows how the materials are circulated.* (*A*) *oversize skip,* (*B*) *catch basin.*



therefore, a natural development, and not only gives better cleaning but possesses much longer life. The selection of either round or angular shot depends on the finish desired and the material to be treated, the round shot generally being restricted to the shot-blasting of non-ferrous castings. Considerable developments have taken place in recent years in the form and nature of the abrasive. Chopped steel wire is claimed to be economical because of its long life, and steel grit is coming into more general use for the same reason.

There are many designs of machines used for propelling these abrasives and each has a particular and useful application, but all fall under one of these two headings: (a) pneumatic, or (b) airless.

The principle of the pneumatic type is that a stream of shot falls into a



chamber through which compressed air is passing, and is then carried along a flexible pipe to a suitable nozzle through which the stream is directed against the surface to be cleaned. The air pressure is usually 20 to 30 lb. per sq. in. for grey iron and non-ferrous castings, and up to 80 lb. per sq. in. for cast steel. After striking the casting the shot, together with any dislodged material, falls through the perforated floor of the cleaning machine. The sand and shot are then separated by a screen and suction dust-extraction system. In this way the cleaned shot is ready for use again, so that the blasting can be carried on continuously.

Shot-blast equipment may be classified into three systems of application as follows: (1) direct pressure, (2) gravity, and (3) suction feed.

Direct Pressure System. The air and abrasive are combined in, and discharged from, a sealed container through a single nozzle.

Gravity System. Here the blasting factor is a gun to which the abrasive is delivered by gravity. Air enters the body of the gun through an air jet, and, combining with the abrasive, drives it out through a discharge nozzle. As the air jet is but half the diameter of the discharge nozzle, expansion takes place and the pressure of the air at discharge is lower than the indicated gauge pressure, although the full force of the air is exerted in the discharge of the abrasive.

Suction (or Syphon) System. In this, a gun is used as in the gravity feed system. A portion of the air energy is exerted to lift the abrasive to the gun, so that the force of the abrasive discharge is not as intensive as in other types.

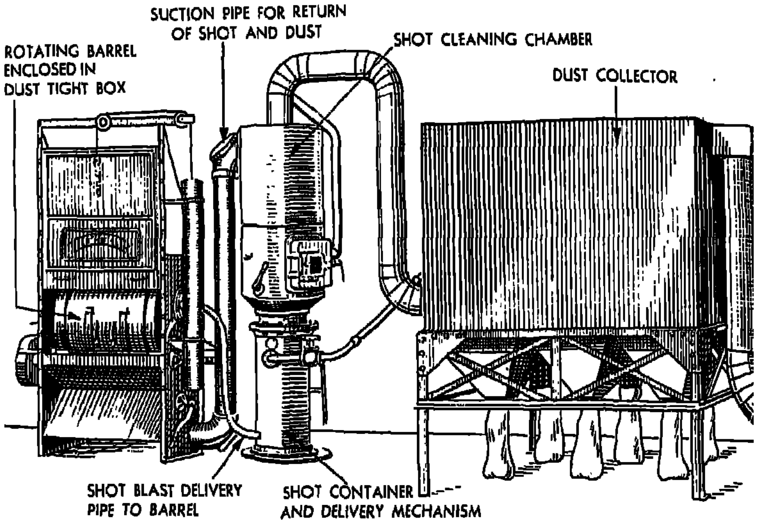
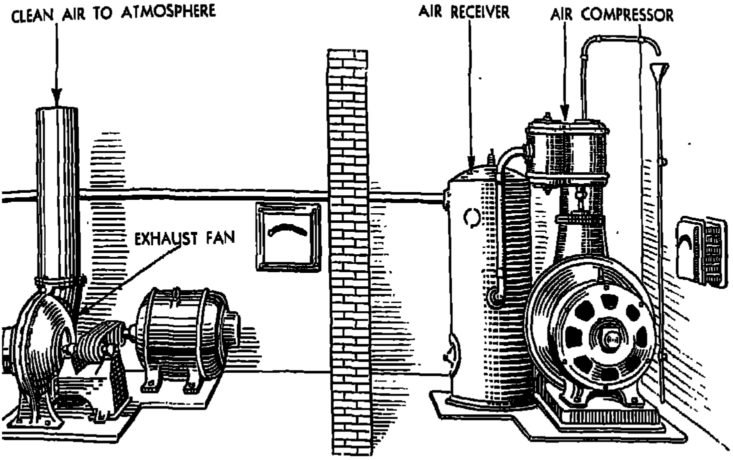

SUCTION PIPE FOR RETURN OF SHOT AND DUST
ROTATING BARREL ENCLOSED IN DUST TIGHT BOX
SHOT CLEANING CHAMBER
DUST COLLECTOR
SHOT BLAST DELIVERY PIPE TO BARREL
SHOT CONTAINER AND DELIVERY MECHANISM

FIG. 12.5. *Complete layout for shot-blasting equipment, using a barrel-type machine. This equipment is particularly suitable for fettling small castings.*

According to the size of casting to be cleaned, the machine may take one of three forms. For small work a barrel rotating on a horizontal axis into which the castings are placed, is a convenient type. The shot is applied through nozzles at either end and, as the barrel slowly rotates, the castings tumble about and thus expose each face in turn to the action of the shot. For larger work, particularly that type which has a large surface area to weight ratio, a table rotating on a vertical axis is the type most favoured. In this design the table is virtually divided into two halves. One half is enclosed in a chamber in which the shot blast can be applied, whilst the other half is exposed for loading and unloading.

The work to be cleaned is placed upon the slowly revolving table and passes through rubber curtains into the cleaning chamber, where it comes under the action of the blast through a series of overhead jets. It is important that the area of table inside this chamber should be equally and effectively covered by the abrasive blast. This effect is obtained, in some designs, by using a cam motion to traverse the jets through which the abrasive is projected, and which is arranged so as to accelerate the movement of the nozzles as they come to the centre of the table. This is necessary to ensure that the speed of travel of the jets is in correct proportion to the table diameter at any point.

As the work leaves the blast chamber it again passes through a rubber curtain and is then ready to be removed, or turned over to



expose fresh surfaces. It then passes once more through the blast chamber.

There are various sizes of both these types of machine, but for most castings of over 5 cwt., it is necessary to provide a special room in which the shot-blast operator works. The operator must be provided with protective clothing, including a helmet with an independent air supply for breathing, and he directs the stream of abrasive from a flexible pipe having a nozzle made from hard, wear-resisting metal. These various types of equipment are illustrated in Figs. 12.5–9, while Fig. 12.10 shows the appearance of the sand and round and angular shot used as the abrasive.

Fig. 12.11 illustrates the mechanism for abrasive cleaning, using the centrifugal force of a high-speed impeller, in place of compressed air, to propel shot against surfaces to be cleaned. The main advantage of this system is that, because no compressed air is used, it is possible to eliminate pressure tanks, nozzle control valves, mixing tanks, air receiver tanks, and air compressors which require large electric motors. This system is applied to barrel and rotary-table types of machines and also to cabinets through which a pendulum conveyor carries the castings.

Typical examples of barrel and rotary types of machine are shown in Figs. 12.12–14. Cleaning is extremely fast, and in the case of the barrel type the loading and discharge arrangement enables conveyors to be used with advantage for feeding the work to and from the machine. These machines are examples of sound mechanical design and efficiency, with adequate protection of bearings against dust, and a completely dust-tight cleaning chamber to prevent pollution of the air.

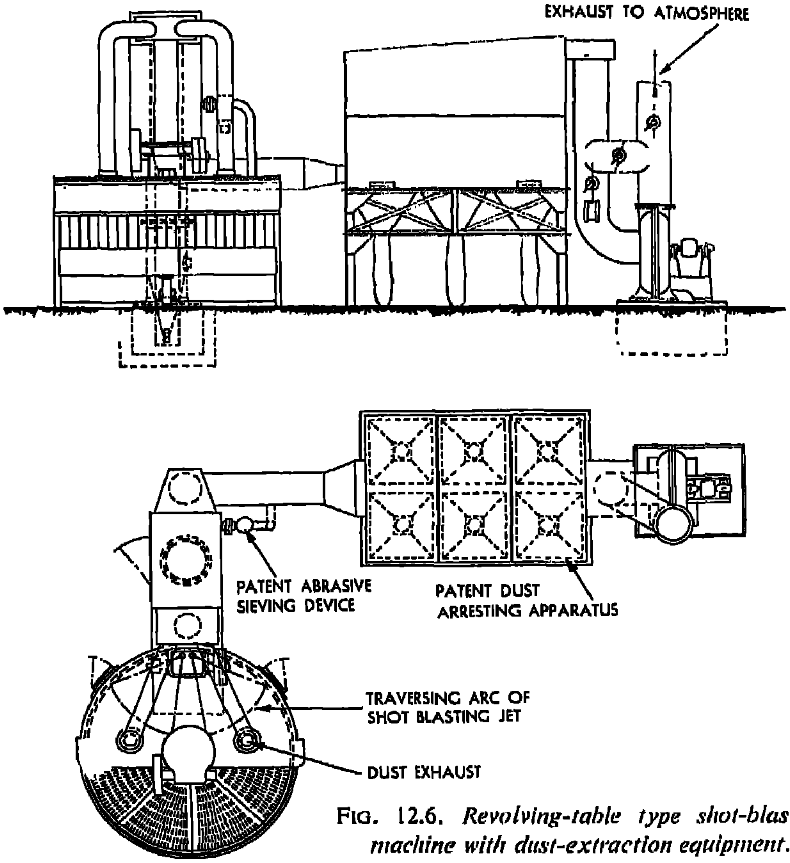

EXHAUST TO ATMOSPHERE
PATENT ABRASIVE SIEVING DEVICE
PATENT DUST ARRESTING APPARATUS
TRAVERSING ARC OF SHOT BLASTING JET
DUST EXHAUST

FIG. 12.6. *Revolving-table type shot-blasting machine with dust-extraction equipment.*

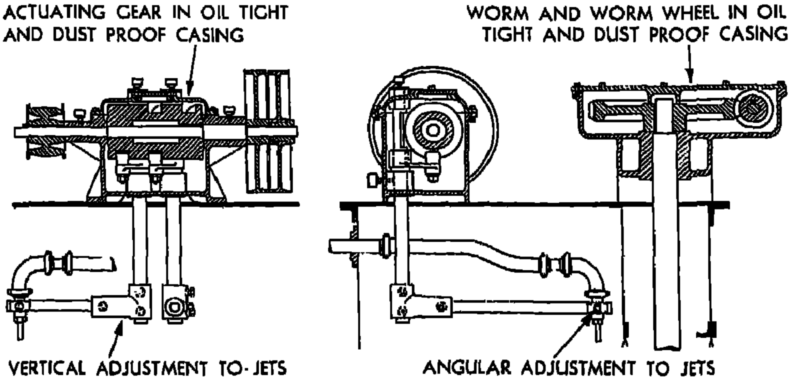

ACTUATING GEAR IN OIL TIGHT AND DUST PROOF CASING
WORM AND WORM WHEEL IN OIL TIGHT AND DUST PROOF CASING
VERTICAL ADJUSTMENT TO JETS
ANGULAR ADJUSTMENT TO JETS

FIG. 12.7. *Operating gear for jets of shot-blasting equipment.*

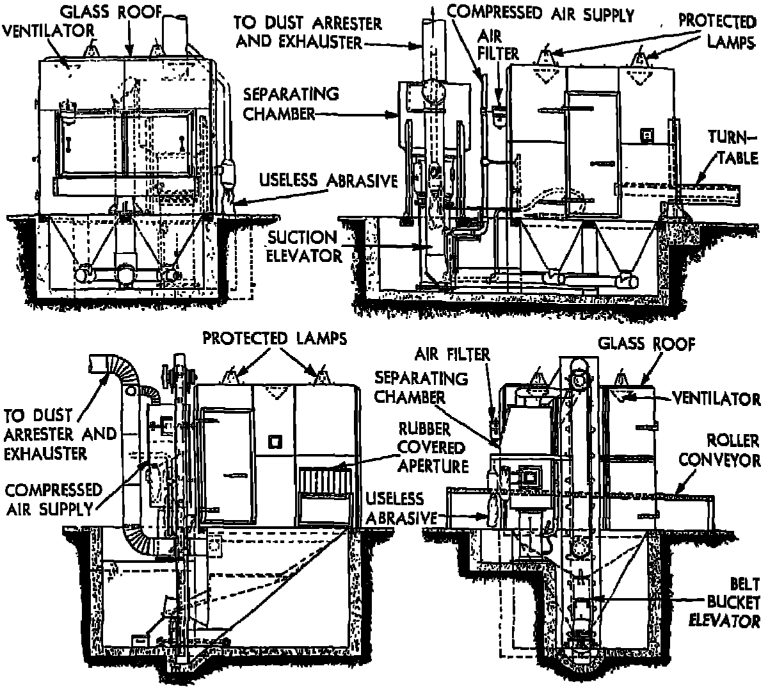
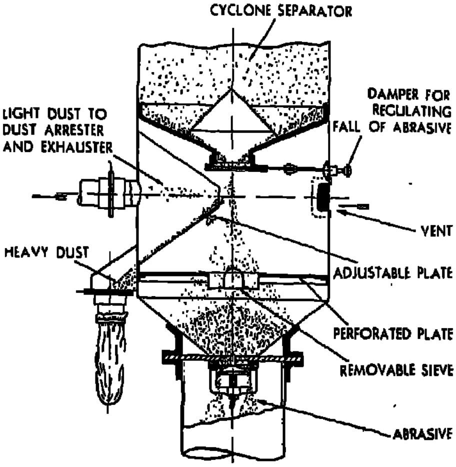


FIG. 12.8. *Sectional views of shot-blast rooms or cabinets suitable for dealing with large and medium castings.* (Below) FIG. 12.9. *Section of cyclone separators for extracting dust from used shot and returning the cleaned shot to the shot-blasting machine for further use.*

The self-emptying action, operated simply by reversing the direction of rotation of the apron in the barrel-type machine, is a very simple method of discharging castings, especially those which are too heavy to be lifted by hand. The power absorbed is surprisingly small. In comparison with a pressure-type shot-blast machine using a $\frac{5}{16}$-in. nozzle, the surface covered is 160 sq. in. against



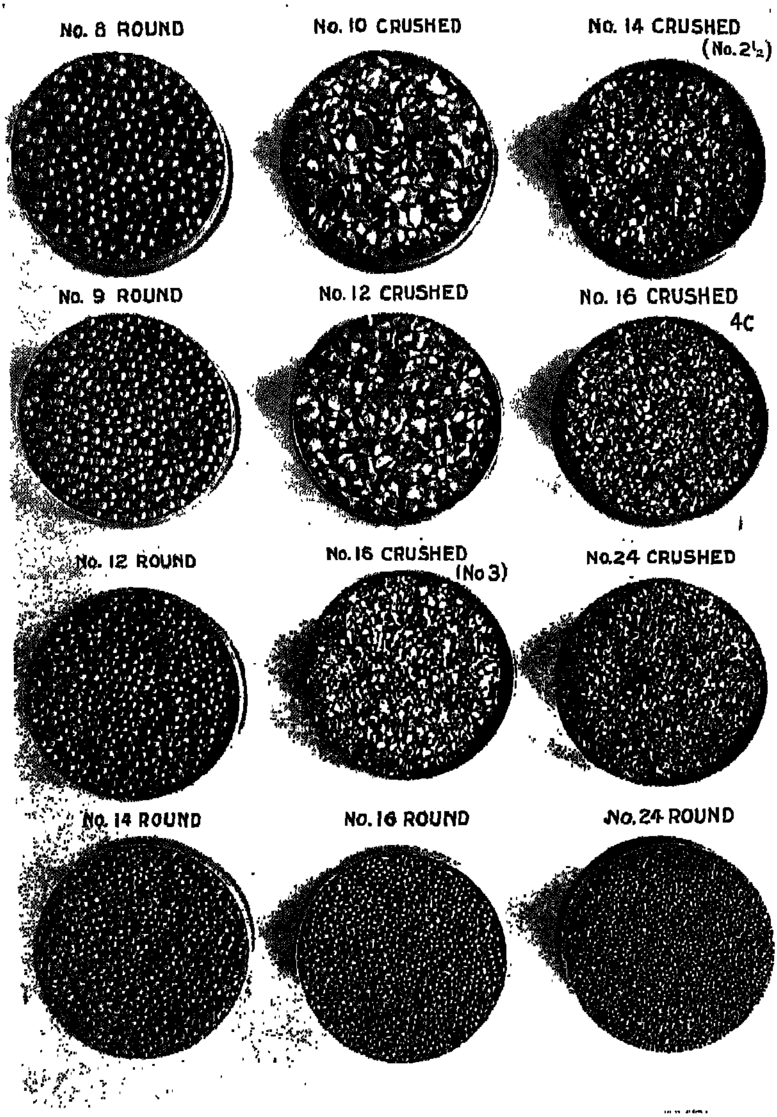


FIG. 12.10. *Various grades of abrasives for shot blasting. The most suitable type of abrasive depends on many factors. Of primary importance is the type of finish that is required; e.g. for a coarse surface No. 9 round might be used. Other important items are cost and the rate at which the castings must be finished in order to maintain a steady output.*

19½ sq. in. with the pressure type, or, approximately, eight times greater at any moment. Only 12½ b.h.p. is used, against 80 b.h.p. in producing the compressed air required to operate a $\frac{9}{16}$-in. nozzle at 80 lb. per sq. in. pressure. The force of impact is approximately the same in both cases.

TUMBLING IN BARRELS

This process, although considerably slower than shot blasting in producing a clean surface, nevertheless possesses some advantages unobtainable in the latter process. The essential difference between shot blasting and plain tumbling is in the speed of the operation. Shot blasting will perform the cleaning in a few minutes, whilst tumbling will take possibly 30 minutes to an hour to do it. This additional time is not altogether a disadvantage, as during the prolonged tumbling about the castings are given a burnished effect by rubbing against each other, and the small, hard, star-shaped pieces of cast iron which are added to the charge. Further, a considerable amount of flash metal is also broken off. In this way any subsequent grinding and chipping are appreciably reduced. In fact, economics may decide as to which process is considered superior, but, of course, in the small foundries it is the tumbling barrel (Fig. 12.14) which provides the simpler and cheaper means of cleaning. Barrels may be hexagonal, square or circular in cross-section and revolve on a horizontal or inclined axis at approximately 10 to 15 r.p.m. A dust exhaust system should be fitted.

CHIPPING

There is a proper way to use a hammer and chisel to remove surplus metal from a casting, and unless this is appreciated a waste of time and

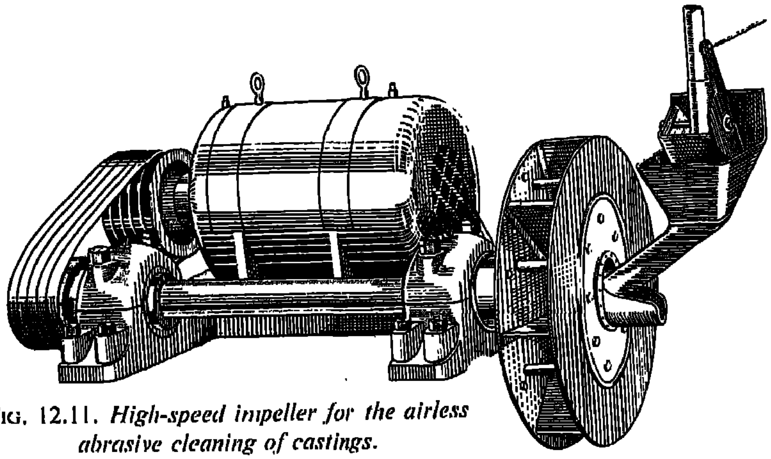


FIG. 12.11. *High-speed impeller for the airless abrasive cleaning of castings.*

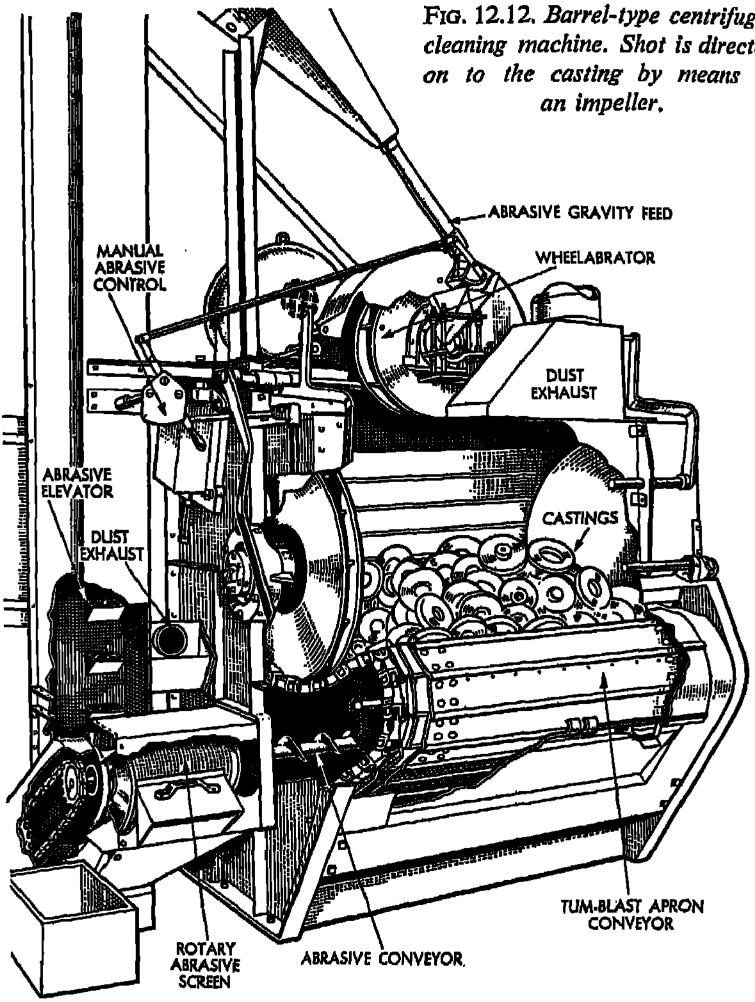


FIG. 12.12. *Barrel-type centrifugal cleaning machine. Shot is directed on to the casting by means of an impeller.*

an unsatisfactory finish will result. Hard, brittle alloys like cast iron will respond to the correct cutting angle or inclination of the chisel to the face of the work (about 60 deg.), with the cut directed towards and not away from the body of metal. Unless this is done pieces are likely to be spalled off, and the surface will be cut unevenly, thus producing the exact opposite of the desired effect. Naturally, the greater the care taken in moulding and coremaking, the less the chipping that will be required to remove metal fins at joints. Twisted mould joints and excessive rubbing of core prints will give the fettler a great deal of extra work. In fact, the

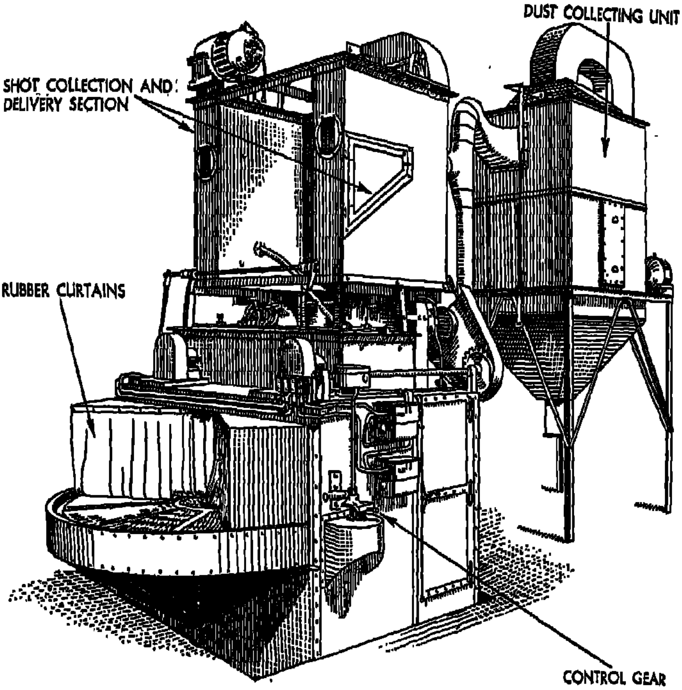


FIG. 12.13. *A 90-in. dia. rotary-table shot-blasting machine using an airless system of shot propulsion, and incorporating a dust-collection system.*

fettler is sometimes expected to exercise the genius of a sculptor in order to rectify the mistakes of the pattern-shop and foundry.

Whilst the hand hammer and chisel are still widely employed and, in many cases of thin, intricate work, are the only tools which can be satisfactorily used, the introduction of the pneumatic hammer usually results in a speeding-up of the operation of chipping. Pneumatic hammers are made in a number of sizes to a variety of designs, but all operate on an air pressure of approximately 80 lb. per in. and deliver from 1,200 to 1,800 blows per minute, with a consumption of between 15 and 30 cu. ft. of free air per minute. The effect of a pneumatic hammer is to give a smaller chip than with a hand hammer, but by virtue of the high speed of the blows and the constant pressure applied the chipped surface is much smoother.

One design of pneumatic hammer is illustrated in Fig. 12.15. Its essential features are a compact and simple operating mechanism, the high-speed blows being delivered by a sliding piston on to the shank of the chisel. In order to reduce vibration and fatigue to the operator, the

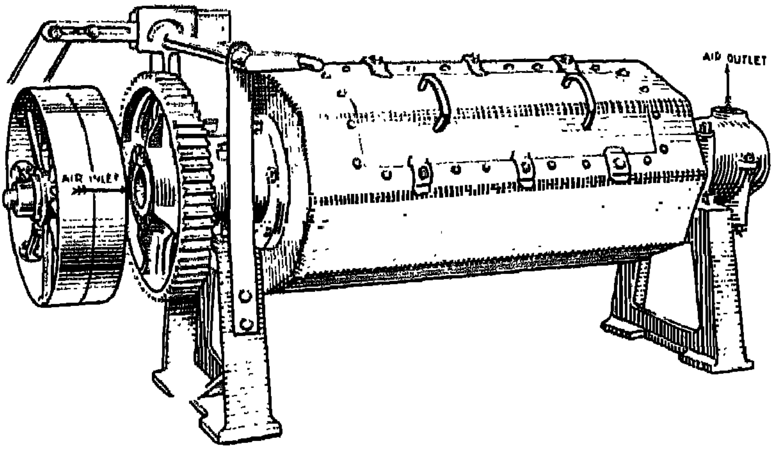


FIG. 12.14. *Hexagonal type of tumbling barrel for cleaning castings. Note the position of the clean air inlet, also the position of the air outlet for dust extraction.*

tool must be as free from recoil as possible and light in weight. All parts subject to wear must be easily renewable, and it is essential that with a tool subject to such internal vibrating stress, maintenance and lubrication should be carried out daily. A trigger-operated needle-valve allows some control over the force of the blows, and this is useful when dealing with a brittle metal like cast iron. With the tougher and more ductile alloys such as bronze and steel, resistance is greater and the cutting is consequently slower; for this reason the larger sizes of hammers can be employed.

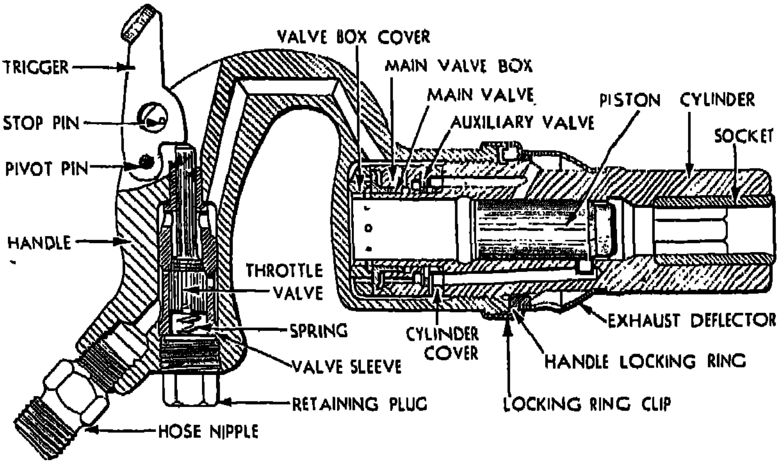


FIG. 12.15. *Sectional view of pneumatic hammer used for chipping castings.*

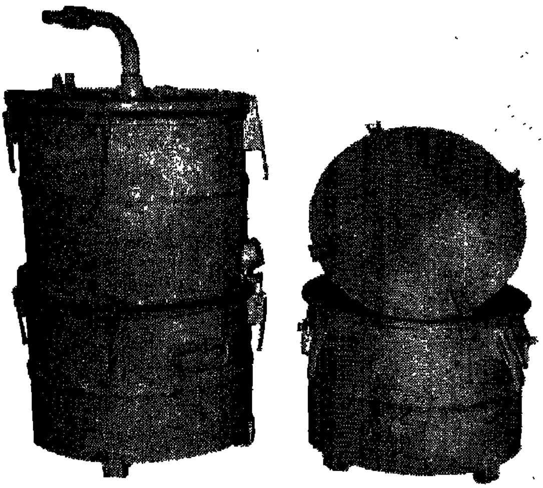


FIG. 12.16. *Simple dust-collector unit for intermittent use, operated electrically by compressed air.*

Generally, the chisels have round and hexagonal shanks, and are located in sockets. The hexagon position prevents a rotation of the chisel. The round portion acts as the true location, and it is important to see that no excessive and uncorrected wear is allowed at this point or breakage will occur. Frequent replacement of the renewable socket bush provides the necessary compensation. Another cause of chisel breakage is the use of an unsuitable steel or wrong heat treatment. There are several reliable chisel steels on the market, and provided the maker's instructions are carefully followed the full useful life of the chisel can be assured. Cutting edge hardness should be about 560 Brinell.

The use of pneumatic chisels gives rise to the production of dust and equipment is now available to draw this away at the source. This is a chisel sleeve moulded in abrasion-resisting rubber. The fine dust is drawn up through two pairs of ducts moulded in the sleeve, one pair taking the dust from the front edge of the chisel and the other pair removing the dust from the lower edge. The ducts lead to a branch tube to which is connected a ⅜-in. bore plastic hose. The sleeves are designed to operate on a vacuum of 5 in. mercury and at this depression pass a volume of 6·5 cu. ft. of air per minute. Small dust collector units are available which will serve an installation of up to eight fettling chisels and these may be operated by a compressed-air ejector or by an electrically driven exhauster.

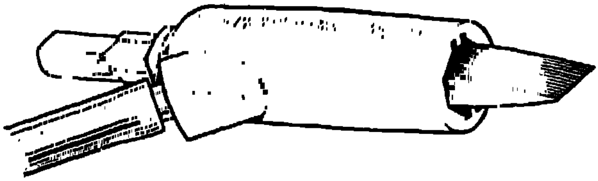


FIG. 12.17. *A rubber fleeting chisel sleeve, which draws up through ducts the fine dust created on both sides of the chisel edge.*

GRINDING

Originally, grindstones were cut from natural sandstone, but they were soft, and difficult to obtain in sufficient quantities. It soon became apparent that there were other natural minerals which offered better cutting qualities, if they could be formed into wheels. These minerals were emery and carborundum, but, again, the difficulty of providing adequate quantities of a suitable grade was the limiting factor. Therefore the production of a synthetic abrasive became inevitable, and from experiments carried out in the electric furnace it was found that materials suitable for each type of grinding could be produced in both sufficient quantity and consistent quality. Two main products are obtained from the electric furnace process: silicon carbide, discovered by Dr. E. G. Acheson in 1893, and crystalline fused aluminium oxide, or alumina, discovered in 1897 by the Ampere Electro-Chemical Co., U.S.A. Silicon carbide is harder than fused alumina, but less resistant to heavy duty on tough metals, so that, generally speaking, for brittle alloys like cast iron, silicon carbide is to be preferred, but for tough metals like steel, fused alumina gives better results.

Whilst the selection of wheels is usually left to the grinding-wheel specialist, it is very useful to understand the principles governing the selection. There are three physical characteristics in a grinding wheel: (a) grains that do the actual cutting, (b) bond that holds the abrasive grains in place, and (c) voids that provide clearance for the chips cut by the abrasive grains. The size of the grains used in wheels for fettling varies from a coarse size, 14, to a medium size, 30. The numbers represent the number of openings per linear inch in the screen used to size the grain. The strength of the bond used is called the grade, or hardness, and will vary according to the ratio of bond material to grain used. In a given type of bond it is the amount of bond which determines the hardness, and for fettling this will vary from medium to hard.

The next factor is the structure, or spacing, between the grains which determines the pores. This may be designated by a numeral such as 0–3 representing close spacing and covering wheels suitable for the high-speed grinding of brass, cast iron and low-carbon steels. Numbers 4–6, medium spacing, cover the high- and low-speed grinding of other alloys. The bond itself is either vitrified or silicate for slow-speed grinding, and either Bakelite or rubber for high-speed grinding. The pores between the grains gradually become filled up during grinding and the surface of the wheel is also liable to be worn unevenly if an operator fails to traverse a casting across the whole face during grinding. To correct this a wheel trueing device is used to recut a true face. Good wheel life can only be obtained if operators attend to these points and use the wheel truer sparingly. The terms high- and low-speed grinding are relative and refer to the peripheral speed of the wheel. Five thousand to 6,000 surface-ft. per minute is slow, whilst 7,000 to 9,500 surface-ft. per minute is high speed.

Naturally, machines which operate at the high speeds require greater rigidity in construction. Several spindle speeds are available to compensate for the reduced surface speed as the wheel wears. It is also necessary to provide safety devices to prevent unduly high speeds being accidentally used. To emphasize the necessity of bearing this point in mind it should be realized that centrifugal force, which is the force that tends to rupture a wheel when over-speeding, increases as the square of the velocity of that wheel. For example, the centrifugal force in a wheel running at 5,500 surface-ft. per minute is 49 per cent greater than in the same wheel running at 4,500 surface-ft. per minute, although the speed is only 22 per cent greater. When the question of the amount of metal removed by grinding is considered, it becomes equally important to see that the correct surface speed is maintained as the wheel wears; with the reduction of the surface speed, the rate of wheel wear increases. As the speed of metal removal by grinding depends on many factors such as the variable hardness of the metal, the width, thickness and irregularity of the metal face to be ground and the pressure applied by the operator, no figures can be quoted.

TYPES OF GRINDERS

A variety of machines is obviously necessary to cater for all the grinding problems encountered in the fettling-shop. The most general type is the double-ended floor grinder, mounting wheels from 12 to 30 in. in diameter, and from 1 to 4 in. wide. These machines may be belt- or motor-driven, with provision for either single or multi-spindle speeds, to run at 6,000 to 9,000 surface-ft. per minute. They are fitted with rests upon which castings are steadied during the grinding operation. These rests are adjustable, so that they may be kept close up to the wheel face as wear takes place. Unless this adjustment is maintained, castings may be jammed between the wheel and rest and cause a serious accident if the wheel bursts. A dust exhaust system, fitted to the steel protecting hood around the wheel, is required by law. A typical low-speed machine is illustrated in Fig. 12.18.

It has been shown by the British Cast Iron Research Association that low-velocity exhaust systems do not remove the very fine particles of dust. These are the most dangerous from the point of view of lung trouble, and after considerable research a device has been developed which places a curtain of fast-moving air between the work and the operator's face. As with the chisel sleeve, the high-velocity air is obtained by working with much higher depression on the suction to the machines. Adaptations of this device are available for the swing grinders now to be described.

Where the size of the casting is too large for the floor grinder, a type known as the swing-frame grinder can often be employed (Fig. 12.19). It is a heavy duty machine with considerable manoeuvrability. In order to avoid chatter and excessive wheel wear, it is good practice to bed the casting to be fettled on to a sand-filled box. This readily accommodates any uneven surfaces and gives firm support. For light grinding, such as the smoothing of surface imperfections and getting round small, irregular faces on large castings, portable pneumatic or electrically operated machines are used. The pneumatic, rotor-type machines are lighter and work at higher speed than the electric grinders, but the latter are capable of heavier duty.

The use of two wheels, a flat one and a cone, increases the utility of these tools, but as the driving power is small their use should be restricted to the limited duty they can perform or a waste of time will result. Whilst some foundries incorporate disk grinding and sanders for ensuring flat surfaces on small castings, these are not normally considered fettling operations, except for die castings, which, for foundry purposes, can be considered in an entirely different category.

SAWING

This is carried out mainly on non-ferrous castings in a variety of ways according to circumstances. The ordinary hack saw is suitable for the very small foundries, but it is too slow and laborious for large numbers of castings. In the latter case a power-driven band saw of conventional design not only performs the operation more speedily but, by virtue of the greater control which can be exercised, allows closer cutting, and, consequently, less waste of metal in subsequent grinding operations. In the die-casting foundry a band saw is essential for the removal of gates and risers. Foundries handling small bronze and brass castings often prefer the "git cutter," or power-driven shear. Where the gates and other wastes are small enough to be handled by this type of shear it offers certain advantages over the band saw, notably greater robustness and appreciably less maintenance. However, it cannot claim the same general usefulness as a band saw. The tooth size and speed are important factors in band saw practice. Where only one machine is used and a variety of alloys is being handled, it is possible to obtain reasonable cutting efficiency if several speeds are available. Modern machines are generally made to give four or eight speeds. The single correct-tooth size and setting, as well as speed, suffice when only one alloy is being used, as is normally the case in the die-casting foundry.

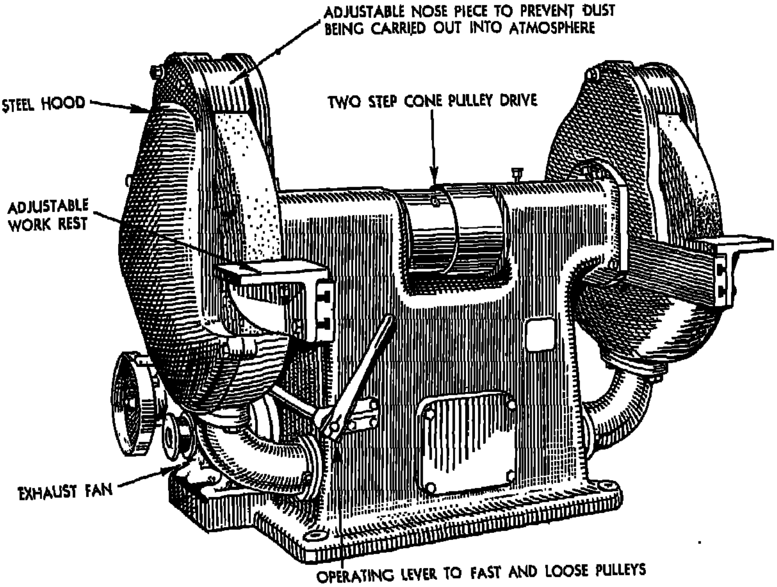

ADJUSTABLE NOSE PIECE TO PREVENT DUST BEING CARRIED OUT INTO ATMOSPHERE
STEEL HOOD
TWO STEP CONE PULLEY DRIVE
ADJUSTABLE WORK REST
EXHAUST FAN
OPERATING LEVER TO FAST AND LOOSE PULLEYS

Fig. 12.18. *Double-ended low-speed grinding machine suitable for belt drive with variable speed pulleys.*

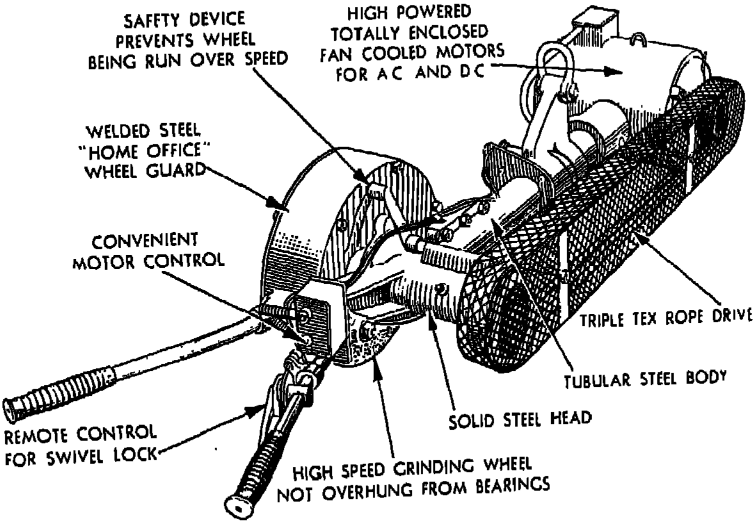

SAFETY DEVICE PREVENTS WHEEL BEING RUN OVER SPEED
HIGH POWERED TOTALLY ENCLOSED FAN COOLED MOTORS FOR A C AND D C
WELDED STEEL "HOME OFFICE" WHEEL GUARD
CONVENIENT MOTOR CONTROL
TRIPLE TEX ROPE DRIVE
TUBULAR STEEL BODY
SOLID STEEL HEAD
REMOTE CONTROL FOR SWIVEL LOCK
HIGH SPEED GRINDING WHEEL NOT OVERHUNG FROM BEARINGS

Fig. 12.19. *Constructional details of the swing-frame grinder. This type is especially suitable for fettling large castings which are difficult to handle.*

A tool for parting off risers in steel and the tough non-ferrous metals is the abrasive wheel. This machine consists of a motor-driven high-speed abrasive disk from 12 to 20 in. diameter and ⅛ in. thick, running at a peripheral speed of 10,000 to 15,000 ft. per minute. The wheel is mounted on an arm which can be swivelled vertically to effect the necessary cutting off. This type of abrasive cutting-off machine was originally designed for cutting up bar material, but if suitable clamping arrangements are provided for holding the castings so that no vibration takes place, the operation is quite successful and extremely fast. It is not economical for small castings owing to the time required for clamping.

The very high speed of operation of the abrasive cutting-off wheel may be applied to small work by arranging the wheel to run in the same way as a circular saw, with the shaft and driving motor beneath the bench top, and pushing the work against the wheel. In suitable circumstances the operator may find it possible to operate in comfort when seated at such a machine. Protection is provided by two or three thicknesses of safety glass suitably mounted between the operator and the wheel. In the last few years there has become available a series of abrasive cutting-off wheels reinforced with nylon or similar material and possessing considerable flexibility. Wheels of this type are virtually unbreakable and are now widely used in special high-speed portable machines for removing heavy fins, risers and other irregularities from castings too large for convenient treatment in any machine.

FLAME CUTTING

The removal of the large feeding heads necessary on heavy steel castings presents a difficult problem. On gears and other circular castings it is sometimes possible to part them off in a lathe. However, on irregular-shaped castings it is usually necessary to employ an oxy-acetylene burner. The castings are first shot blown, particular care being taken to remove any sand at the neck of each head to be cut off. If any mould-facing material is burnt on this must be removed with hammer and chisel so that the flame can play on clean metal and so avoid the formation of slag. Because of the high shrinkage of steel, it is sometimes found that cavities are left in the risers. If the cutting flame reaches one of these holes it is necessary to cut round it, or the rate of cutting will be slowed down owing to the excessive formation of oxide scale. Whilst experience enables operators to quickly overcome any difficulties from variable metal composition, metal thickness, oxide formation, etc., it is important to discourage any attempts to force the rate of cutting, which result in the waste of acetylene and oxygen.

The local application of so much heat as that used in flame cutting will set up strains in a casting. These strains may cause warping, or, in

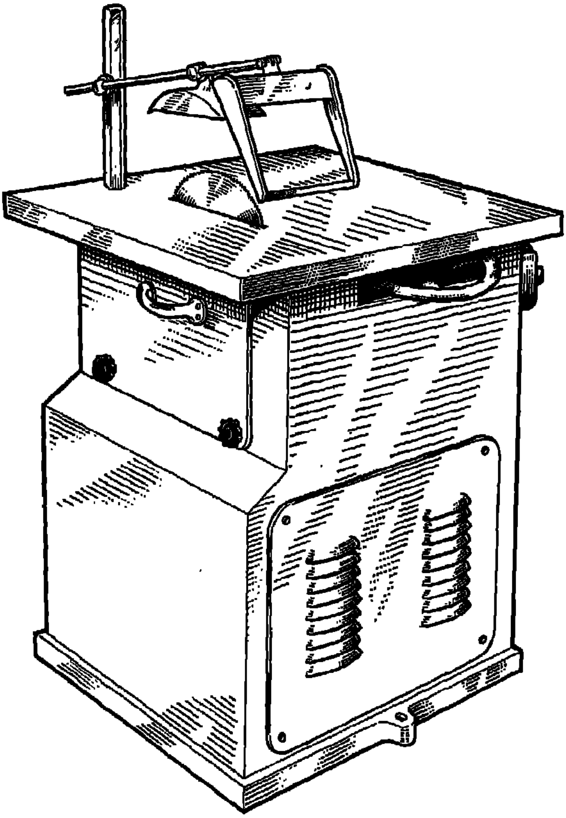


FIG. 12.20. *Circular-saw bench for fettling castings.*

intricate designs, cracks, and it is necessary, therefore, to anneal castings to relieve these stresses. This is carried out at approximately 860 degrees C., and has the added advantage of normalizing the structure which may be locally hardened around the edge cut by the flame. The size of burner and tip, together with the amount of gas which should be used, are available from the accumulated experience of the makers of this equipment, and little is to be gained from individual experimenting. A development which is being used in steel fettling shops after risers have been cut off with the oxy-acetylene torch involves the use of a carbon electrode to arc on the riser and so give very localized melting. The melted steel is blown off with compressed air and the riser can thus be trimmed down very nearly to the contour of the casting with much less effort than trimming with a pneumatic chisel.

PICKLING

This is a process which has declined in favour of shot blasting, chiefly owing to the slowness of the operation and the inconvenience of using acid solutions. The acids used are sulphuric and hydrofluoric for cast iron, and nitric, or a mixture of nitric and sulphuric, for brass. Sulphuric acid attacks metal, and in doing so loosens any adhering sand, whilst hydrofluoric acid attacks the sand alone, and for this reason, although somewhat slower in action, is usually preferred. A commonly used acid solution is one part of 48 per cent hydrofluoric acid and 25 parts of water. A lining of lead, or other suitable acid-resisting material, must be used for the tanks which hold the acid. Further tanks containing alkaline solutions and, finally, hot water must be provided to neutralize the acid remaining on the castings when they are removed from the pickling process. To reduce the irritation of the fumes which are given off, the whole process should be carried out in an open-sided, or well-ventilated, building.

SAFETY AND HYGIENE

The dangers associated with the various fettling operations can be materially reduced by the provision of safety appliances and the proper education of personnel. This latter is now continually emphasized throughout engineering works by posters, but much can be done by those in charge insisting on the regular use of all safety measures provided, particularly by young persons. Goggles, or masks, for protection against flying particles are apt to be discarded in hot weather, or if the lighting is inefficient, but the danger of such actions is that the intermittent use of safety methods leads to a false sense of security.

Every fettling shop should be provided with an adequate dust collection system for the grinding machines, tumbling barrels, and shot-blast equipment. Many systems are in use, the combination of a cyclone for heavy particles and linen filters for fine ones being particularly efficient. Dust accumulations should be regularly cleaned from these collectors. There is a tendency for more wet filters to be installed as the air exhausted from these contains no dust particles whatever and the sludge is handled without promoting further dust trouble.

Fettling shops are closely affected by the provisions of the Iron and Steel Foundries Regulation (1953). Under the heading "Dust and Fumes," this states:

"All dressing or fettling operations shall be carried out—

(a) In a separate room or separate part of the foundry suitably partitioned off; or

(b) In an area of the foundry set apart for the purpose: and shall so far as reasonably practicable, be carried out with effective and suitable local exhaust ventilation or other equally effective means of suppressing dust, operating as near as possible to the point of origin of the dust."

From this chapter it will be evident that fettling is an important operation, and, like moulding and coremaking, requires skill and dexterity if the product of the foundry is to be offered with the best appearance and an ever-increasing saleability.

Chapter 13

FOUNDRY MECHANIZATION

THIS chapter deals with the mechanical handling, or movement by mechanical as opposed to manual means, of materials throughout the foundry. The phrase "foundry mechanization" is frequently used to embrace both handling equipment and specialized machines such as moulding machines which are dealt with elsewhere in this book. In this chapter, however, we are concerned only with the mechanical handling equipment.

Handling aids may be applied to the production of castings in a variety of ways: some foundries can justify greater application of such aids than others. For example, a small foundry using floor moulding and specializing in "one-off" castings of widely varying types could only introduce a small variety of handling aids common to any normal factory. A foundry engaged in the mass production of standardized castings, however, would require complete mechanization of all aspects of its production and would make full use of all handling aids available (Fig. 13.1). Although many readers will be familiar with the various types of handling equipment available to the foundry, a short description of each may be found useful before we proceed to examine each section of the foundry from the mechanical-handling aspect.

CONVEYORS

Roller Conveyor. Widely used in the foundry for the conveyance of moulds and empty boxes, it is important that the correct design of roller conveyor is chosen for each application. Rollers incorporating non-precision pressed-steel races may damage completed moulds by vibration, and it is recommended that moulds in process awaiting pouring should be carried on high-quality roller track. Pressed-steel races should not be used at the pouring point or where any excessively heavy duty is involved, such as receiving the empty boxes from the knock-out. In these instances a heavy-duty roller, usually fitted with permanently dust-sealed precision ball bearings, should be used (Fig. 13.2). The rollers, particularly when handling moulds, should be as closely pitched as possible to provide a smooth-running surface, and turntable junctions are in general preferable to switches in that they take up less room. Fixed junctions, although very often used, do not in general provide such a smooth path for the mould boxes as either the roll-over switch or turntable. When runs of precision roller are used side by side for pouring, it is important that the ends of the rollers are protected from metal splashes as these will quickly render a roller completely unusable.

Power-driven roller conveyors are sometimes used, particularly for returning empty mould boxes to the moulding machines. One type of roller conveyor takes the form of a double-chain slat conveyor with rollers, which are free to revolve, taking the place of the slats. Thus it is possible to place a box on this conveyor which will carry it to the desired point when it can be stopped in any position without stopping the conveyor itself. Another type employs chain sprockets fitted to the roller spindles and a simple chain drive from one to another. When handling moulds it is normally intended that the moulds should be pushed along the roller conveyor by the operators. While a conveyor can be given a slope, this should only be such as to assist the operator to push the moulds and not sufficient to permit the moulds to travel uncontrolled down the conveyor. Uncontrolled travel, however, is satisfactory for the return of empty boxes.

Belt Conveyors. Canvas-reinforced rubber belts are used for handling sand and should be of more than ample width for the capacity required in order to avoid spillage and to provide for occasional overloads. It is important that the carrying idlers, whether troughed or flat, and the return-belt idlers should be provided with totally enclosed dust-sealed bearings. Adjustable scrapers or revolving brushes should be fitted immediately under the head pulley to clean the belt and avoid spillage from the return side. The drive must be easily accessible; in many cases it is mounted on a removable bedplate to allow for ease of maintenance and a quick changeover in the event of failure. Where the belt is distributing sand to a series of moulding machines, it must be flat in order to allow for ploughs delivering the sand to each hopper and therefore must be of ample width to ensure that no spillage occurs. Inclined belts should not be allowed to rise at an angle of more than 18 deg. from the horizontal. Where sand is discharged on to a belt conveyor from the knock-out, a heat-resisting rubber and canvas belt may be used; it must be of more than ample width to allow for intermittent heavy overloads, and since this is the one belt in the foundry which is subject to the most arduous use and to the greatest possibilities of damage, it should be as short as possible and made continuous. It should not incorporate a belt fastener.

Steel Band Conveyor. This is a type of belt conveyor using a continuous steel band in place of the rubber and canvas belt. It is usually used in the foundry for conveying cores and provides a firm flat surface which minimizes the possibility of damage to delicate cores.

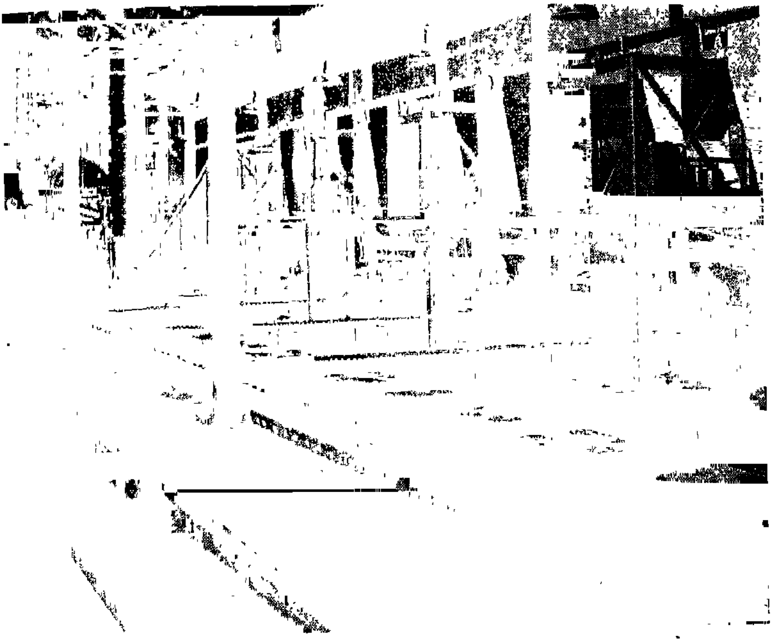
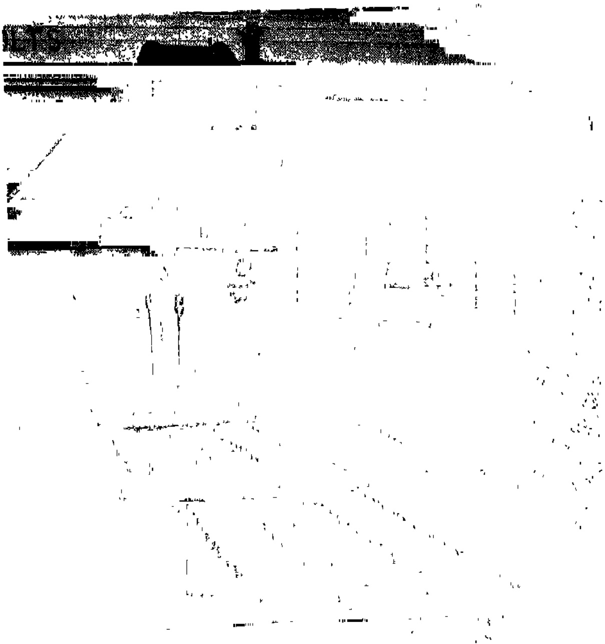


FIG. 13.1. *Part of a fully mechanized foundry showing pallet-type mould conveyor, roller conveyor, main sand-distribution belt and moulding-machine hoppers.*



(Right) FIG. 13.2. *Heavy-duty precision roller conveyor in use in a mechanized foundry.*

Apron Plate Conveyor. This is a double-chain conveyor, the chains supporting overlapping plates forming the carrying surface and overlapping side plates containing the load and preventing spillage (Fig. 13.3). This type of conveyor is frequently used for handling knock-out sand and for receiving sand and castings from, say, an automatic knock-out.

Slat Conveyor. This is also a double-chain conveyor, the carrying surface consisting of a series of steel or timber slats which do not overlap. It is therefore unsuitable for carrying sand. This type of conveyor is used for handling empty boxes and castings (Fig. 13.4).

Overhead Chain Conveyor. The overhead chain conveyor is normally used in the foundry as a casting cooling conveyor to transport castings from the knock-out to the fettling shop, at the same time cooling them on the way (Fig. 13.5). The overall length and speed of this conveyor is dictated by the cooling time required for the castings. The conveyor can be

FIG. 13.3. *An apron plate conveyor of the double-chain type handling hot sand direct from the knock-out station.*

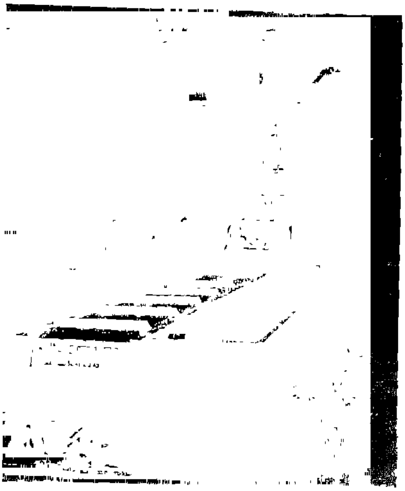


FIG. 13.4. *A steel-slat conveyor handling castings from an overhead casting cooling conveyor into the fettling shop.*

made of any length by providing synchronized or balanced drives. It also has the advantage of taking up floor space only at the loading point, the rest of its length being run overhead. It can be also used as a mould conveyor or for carrying cores. In these cases it is very often known as a "pendulum" type conveyor.

Bucket Elevator. It is frequently necessary, from space considerations, to incorporate a bucket elevator in a sand plant. This will be handling either new sand, bonded sand ready for distribution to the moulding points, or screened knock-out sand. A belt-and-bucket elevator is normally used and it is important to ensure that the sand is correctly fed, usually into the third bucket up from the tail pulley. In handling bonded sand provision must be made to ensure that the buckets are completely cleared on discharge and that the sand is aerated before being fed on to the distribution belt, since the sand will tend to have "packed" in the elevator buckets. It is usually preferable to avoid using this unit for handling prepared sand. Provision must be made for cleaning spillage from the boot, and a suitable slotted tail pulley must be provided to prevent build-up of sand.

Pallet Conveyor. These are used almost exclusively for handling moulds. This type of conveyor varies in design detail from one installation to another, but basically consists of a series of overlapping plates interconnected by a continuous chain or drawbars and guided round a horizontal path (Fig. 13.6). The plates themselves may be provided with runners, or the runners may be fixed to the track, providing a rolling surface for the plates. The plates for these conveyors are of cast iron; they are always machined on their underside running surfaces and frequently machined on their top carrying surfaces. This type of conveyor is sometimes driven by means of a corner sprocket, but more usually by a caterpillar drive mounted either vertically or horizontally.

SKIP HOISTS

These units are frequently used for cupola charging and consist essentially of a skip which is hoisted up an inclined track and automatically tipped at the top of its travel. The return of the skip to the lower level for re-charging may be done either automatically or by manual operation of the hoist control. Normally the entire weight of the skip and contents is lifted by the winch, but it is sometimes possible to provide either balance weights or two skip buckets working in balance with each other. The latter type of installation is usually only used for very high rates of charge. Another type of skip hoist designed specifically for cupola charging incorporates, in place of a tipping skip, a drop bottom bucket. A single unit of this type is frequently mounted in such a way as to swivel and feed either of two cupolas.

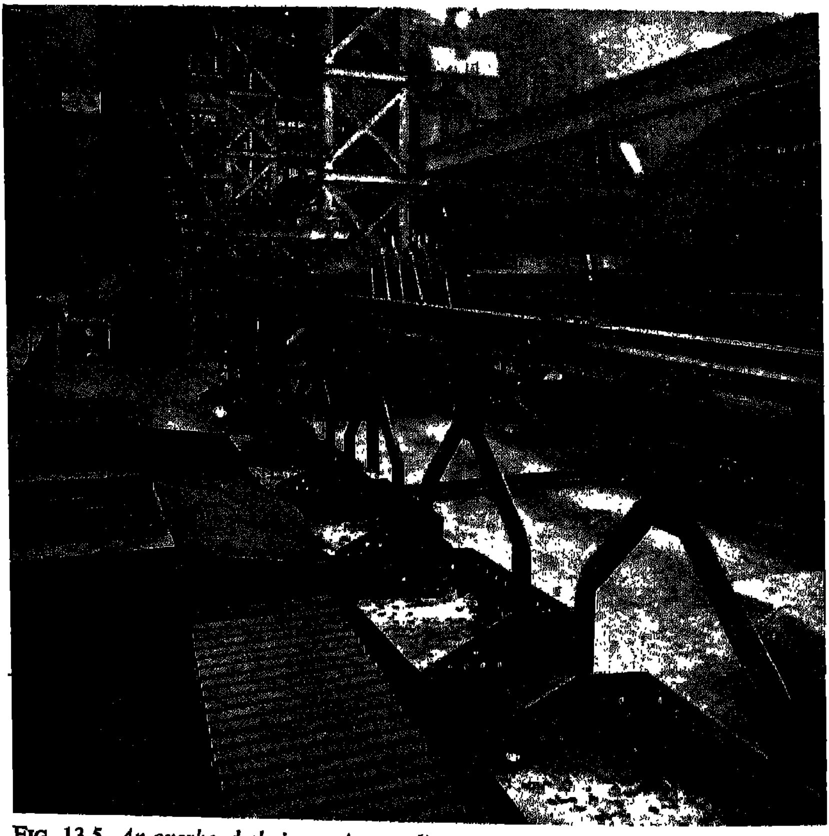


FIG. 13.5. *An overhead-chain casting-cooling conveyor, showing how the skips are positioned relative to the knock-out.*

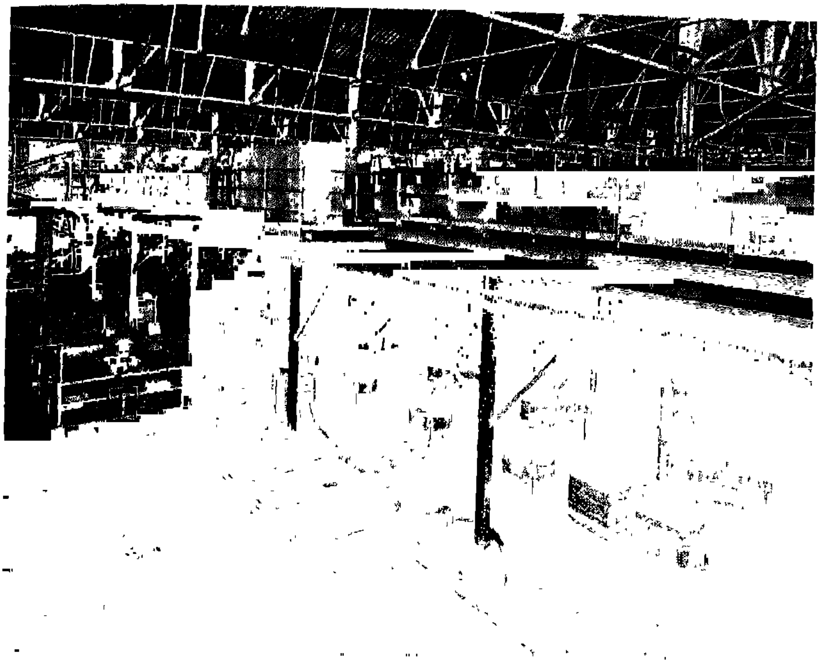


FIG. 13.6. *Part view of a fully mechanized foundry, showing pallet-type mould conveyor in the foreground.*

SAND HANDLING

In a fully mechanized sand plant the new sand will be received through a grid and elevated by a belt-and-bucket elevator to the new sand hopper or hoppers. New sand may be fed slowly and regularly into the existing sand system at a convenient point between the knock-out and the mills, care being taken that it has been thoroughly screened. Several types of mill are available to the foundryman, of either the batch or continuous type. Where continuous mills are used it is essential that close control is kept on the quality of the sand, so that adjustments can quickly be made to the moisture content, bond additions, etc. Batch mixers can be incorporated into a continuous system if two mixers are employed, fed alternately. Batch mills have the advantage that it is possible to vary the milling time to suit different qualities of sand.

The sand is fed from the mill to the main distribution belt, and frequently is passed through an aerator first to ensure that any hard lumps which may still be present are broken up. Several designs of aerator are used, one type consisting of a revolving squirrel cage containing specially hard steel cross-bars. These are made easily renewable, since abrasion at this point is very severe. The sand is then carried by the distribution belt to a series of ploughs, each plough feeding a moulding-machine hopper. These ploughs may be operated manually by an attendant who controls the sand feed to each from an overhead walkway, or by the moulders themselves from floor level. Automatic feed to these hoppers can also be arranged by bin level indicators operating suitable solenoid-controlled ploughs. Automatic feed has also been achieved by fitting permanently fixed ploughs, each "siphoning" off a preset width of sand from the flat belt. This has worked satisfactorily, but it is important that the sand feed should be reasonably constant in quantity and evenly spread over the belt.

Sand spillage from the moulding machines falls through a grid in the floor to a return sand belt running beneath the machines. This belt also receives any tailings from the head end of the overhead distribution belt. The return sand belt normally feeds on to the tail end of the short, heat-resisting knock-out belt, and thus spillage is re-absorbed into the sand system. Before the sand is returned to storage from the knock-out belt, all metal must be removed, hardened lumps and other foreign bodies must be screened out of the sand, and the sand must be allowed to cool. A magnetic separator is therefore normally introduced as soon as possible after the knock-out belt; this can be of the magnetic head pulley type or of the transverse-belt type, generally mounted immediately above and at right angles to the conveyor. This unit must not be fitted in a position where the scrap metal is still liable to be red-hot, however.

A recent type of magnetic conveyor head does away with the head pulley and substitutes a series of non-magnetic rollers. Fitted between the two strands of belt is a stationary coil unit which can provide a great depth of magnetic field and therefore much more powerful metal extraction than the normal magnetic head pulley. The transverse-belt type of unit consists of a short length of conveyor belt to which is fitted inductors which become magnetized when passing through the field of the magnet unit mounted between the top and bottom strands of the belt. The tramp metal is therefore lifted out of the sand as the inductors pass across the carrying belt and drop the material into a suitable chute at the side of the main conveyor. These units may also be mounted in line with the main conveyor, in which case they should run slightly faster in order to avoid damage when picking up long pieces of tramp metal or core wires.

The sand must now be screened to remove any further pieces of metal and hard lumps of sand. A rotary screen is normally used to help break up the larger lumps and also to assist in the cooling of the sand. These screens are usually hexagonal and fitted with perforated plate or heavy-wire mesh panels of robust construction. The screens are made either parallel-sided and set at a slight angle, or in the form of a cone with the axis horizontal. It is usual to fit a vibrating screen at some point in the system after the rotary screen and before the return of the sand to the sand storage hopper. It is desirable to avoid having bucket elevators if possible, and to ensure that sufficient cooling time has been allowed for the sand. Cooling is assisted, of course, by screening and by the fitting of combs on certain parts of the belt system which will turn the sand over.

MAIN STORAGE HOPPERS

The main sand storage hoppers may be square or circular with a tapered bottom feeding on to a rotating table discharge; or they may be rectangular in shape, again with a tapering bottom, the floor of the hopper consisting of a belt conveyor by which means the sand is discharged (Fig. 13.7). In the former case a cone is either fitted to the top of the rotary table or suspended in the hopper itself a few feet above the

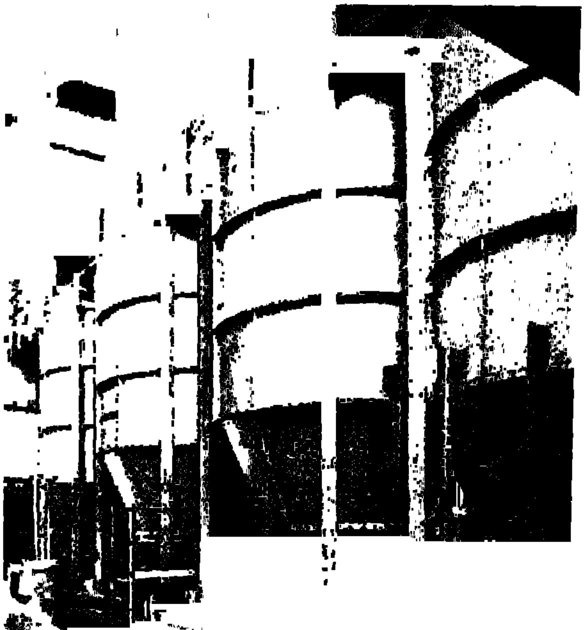


FIG. 13.7. *A row of 50-ton sand-storage hoppers. Each is provided with a rotary discharge table.*

rotary table; it has been found that the latter method has advantages in taking some of the load of sand off the table and giving a better discharge flow. Rectangular hoppers may be provided with a number of flat belt discharge conveyors; thus the rate of feed can be varied and this method frequently helps to break any bridging of the sand which may form.

Moulding-machine hoppers can be provided with either a duplex gate-valve discharge or a short length of belt conveyor. Bridging and funnelling is frequently experienced in these hoppers and various methods have been used to overcome this trouble. These include the fitting of electric or air vibrators to the side of the hopper, to be operated only when the discharge is taking place. (If allowed to operate continuously they may have the effect of packing sand and defeating the object of their fitment.) Making one or more sides of the hopper from a flexible substance such as conveyor belting has also been found satisfactory in some cases. Inflatable panels fitted to the inside of the hoppers have been used in the United States but at the time of writing do not appear to have been used in this country.

Small hoppers must also be provided in the sand system to carry the additions of clay, coal dust and other bonding material which may be required. These are usually situated over the belt conveyor feeding the mill and a variable trickle feed provided.

METAL HANDLING AND POURING

In the stockyard electric overhead travelling cranes or mobile jib cranes are used to stack the material and sort it into bins from which the cupola charges are made up. The charges are made up from these bins into skips which may be weighed by feeding them on roller conveyor to a static platform weigher, or on an overhead monorail, and the skips then tipped either into charging buckets or direct into the cupolas if the site levels permit this. The charging bucket may be of the drop bottom type and handled either by a skip hoist charger as described above, or by an overhead telpher charging system (Fig. 13.8), particularly when the stockyard is remote from the cupolas. Fork-lift trucks with special attachmernts including a rotating head, may be used under good running-suface, conditions for the handling of stockyard scrap.

Once the charge has been melted in the cupola the molten metal is required to be handled to the moulds themselves, and the method adopted for pouring will naturally depend on the type and size of the castings produced. In a fully mechanized foundry the moulds ready for pouring will be moving on the pallet-type mould conveyor past a pouring point. In this case, the man using either hand-shank or geared ladle hoists, suspended from overhead runways, will stand on a pouring platform at

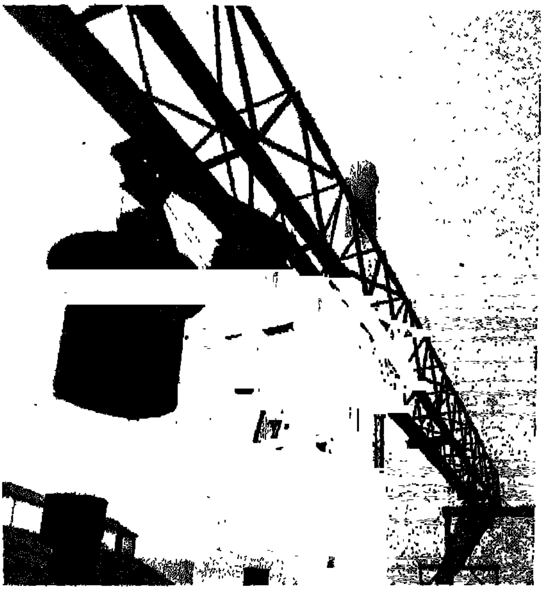


FIG. 13.8. *Overhead telpher cupola charger, handling a drop-bottom charging bucket from the stock-yard to the cupola.*

the same level as the pallet-type conveyor, or on a special slat conveyor moving at the same speed as the pallet conveyor. Rolled-steel-joist runways are commonly used for carrying ladle hoists and trolleys and it is preferable that moving stub switches rather than fixed junctions are incorporated in such a runway since they provide a smooth and positive path for the trolley. The twin-bar type of runway (Fig. 13.9) can often be used with great advantage, employing heavy parallel-faced trolley wheels and allowing much greater ease of movement than the rolled-steel-joist runway. Electric or air-operated hoists are frequently used for heavier ladles. Driver-controlled ladle hoists controlling both the hoisting and tilting motions of the ladle have been designed to travel with a moving mould conveyor or past a static row of moulds. These units are mounted on floor rails or suspended from a double overhead runway to provide the necessary stability.

CORE HANDLING

Core sand is not normally required in such large quantities as moulding sand, and it is, therefore, unusual fully to mechanize the transport of this material. Skips and barrows are employed for conveying the new sand to a drier, should drying be necessary, from there to the mixer, and finally to the coremaking stations. Where the quantity to be handled warrants mechanization, a conveyor system may be employed for the new sand in the same way as for moulding sand. Dry core sand can be handled pneumatically and may be elevated through pipes by compressed air to a storage hopper above the mixer. The sand taken to prepare a batch of core sand should be accurately measured, and this is sometimes done by filling a skip known to hold a suitable weight of sand and discharging this into the mill. A more rapid method is shown in Fig. 13.10, where an automatic measuring hopper is situated above the mixer and movement of the handle discharges a predetermined weight of sand.

Because mixed core sand containing oil rapidly dries out, especially in hot weather, it should be transferred to the coremaking stations as rapidly as possible in bulk, and after mixing kept covered to the maximum extent possible. In some cases the core sand is circulated to the coremakers in covered buckets on an overhead conveyor, the bucket being tipped up by the coremaker when the supply of sand needs replenishing. In other cases the mill is mounted on a platform, and the core sand delivered to hoppers above the coremaking stations by barrow. Although the above remarks assume that an oil-sand core mixture is being used, they apply equally where a clay-cereal binder is employed. In this case, however, air-drying may not be so rapid, and it may be possible to feed the core sand to the coremakers on a belt conveyor, ploughing it off into hoppers as required.

The green cores must be transported from the coremakers to the drying stoves, and for this a steel band conveyor, a canvas or rubber belt supported throughout its length, or a pendulum-type overhead conveyor is

FIG. 13.9. *Twin-bar runway being used in conjunction with a rolled-steel-joist runway to provide an efficient pouring system.*

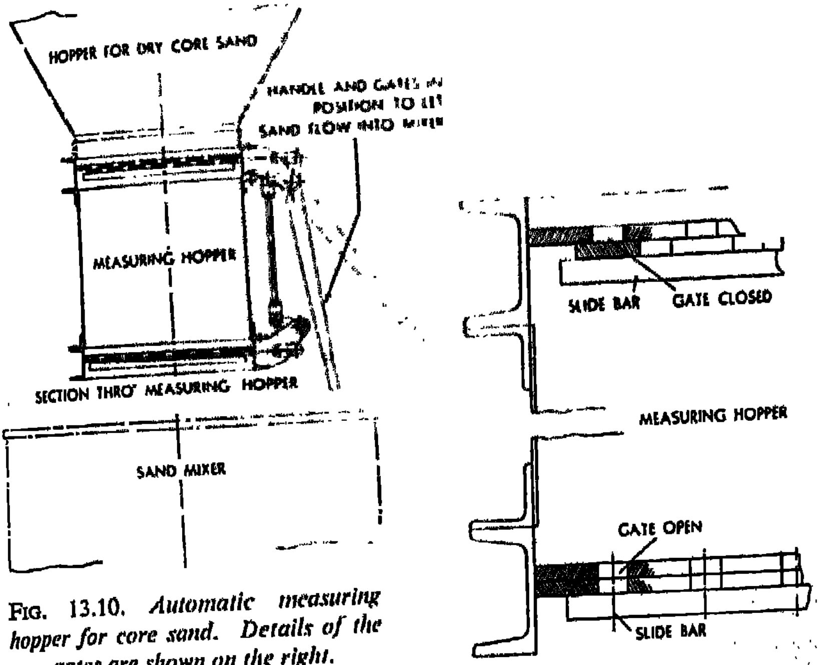


FIG. 13.10. *Automatic measuring hopper for core sand. Details of the gates are shown on the right.*

usually employed. The conveyor carrying the green cores must run smoothly, as in this state they are fragile and rough handling can be the cause of distortion and breakages. If trouble from this source is experienced, and it is not possible to improve the conveyor, a modification to the core mixture to increase its air-drying properties or green strength may offer a solution.

For transport of the dried cores to the inspection and on to storage or to the core-setting stations, an overhead pendulum-type conveyor is very satisfactory, as no floor space is required. The cores can make a complete circuit and remain on the conveyor until required. Other conveyors, such as the belt and steel band types, are also used for the delivery of dried cores, and where a further operation such as dipping, spraying or blacking is necessary, the cores may be removed and later returned to the same conveyor.

MOULD HANDLING

The moulding machines themselves are described in Chapter 10. We shall assume here that the cope and drag have been removed from the moulding machine (by air hoist or manually) and deposited on roller conveyor. (We are still referring, of course, to a fully mechanized foundry.) Where floor moulding is concerned, this operation is done either by hand or by the assistance of the shop crane.

The moulds may be closed either by hand or by the use of a short overhead runway and air hoist unit, which would allow the cope to be lifted, turned over and lowered gently on to the drag. The complete mould would then be pushed by hand on to the mould conveyor. If this is of the roller conveyor type, a turntable will probably have been used at this point; if it is of the pallet type then it is sufficient to push the mould directly on to the flat pallets. The moulds are carried by the mould conveyor to the pouring point and then usually through a fume-extraction tunnel to the knock-out position. Where roller conveyor is used, the storage lines will be filled up and poured in rotation, each line being subsequently fed to the knock-out. Core setting is normally carried out during the transfer from the moulding machines to the main mould conveyor, the latter only handling closed moulds.

Where a continuously operating mould conveyor is used, it is obviously necessary to have a continuous supply of metal. If this is not possible, a compromise can be achieved by having a series of short "trains" of moulds, each being moved into position at the pouring point as soon as metal becomes available. This also means, of course, that each train must be completely filled with completed moulds before it can be moved away from the moulding machines. The rate of moulding in this case will therefore depend on that of the slowest moulding-machine operator.

THE KNOCK-OUT

The simplest method of delivering completed moulds to the knock-out is to push them on a roller conveyor. Where a pallet-type mould conveyor is used, the moulds may be automatically transferred from the pallet to the knock-out grid by means of pneumatic or hydraulic pushers. Again, the moulds may be lifted by means of a hoist incorporating a pneumatic vibrator which will allow the sand and castings to fall on to a static grid. With a pendulum-type mould conveyor handling smaller moulds, these are often lifted by hand on to the knock-out grid. Where snap flasks are used, the individual pallets of the mould conveyor are arranged to hinge or tilt at the knock-out point and allow the sand and castings to fall on to a sloping vibrating grid. This will deliver the sand on to a knock-out belt while the castings, runners and risers will be delivered from the end of the sloping grid.

In a more highly mechanized plant, fully automatic knock-outs have now been developed in which the cope is automatically gripped and removed to a return box conveyor, while the drag is vibrated until the sand

and castings have fallen through to a sloping vibrating grid. This again will deliver the metal to one point and the sand to the knock-out belt, the lower half of the box being transferred to the return box conveyor.

The handling of empty boxes back to moulding stations can be done either by replacing them on the continuous circuit of a powered mould conveyor, or by running them back on roller conveyor, the boxes moving by gravity or along a horizontal conveyor suitably powered.

There are many designs of vibrating knock-out, and it is not proposed to describe these in detail here except to record that they are generally divided into two main types: (1) a mechanically jolted grid usually operated by an eccentric shaft; and (2) a grid vibrated by electrical impulses.

A retaining hopper provided with a rotary-table discharge is sometimes mounted beneath the knock-out grid although it is more usual for the sand to fall directly on to the knock-out belt, which should at that point be supported by close-pitched idlers. The castings are transferred into skips or on to a casting cooling conveyor for transfer to the fettling shop.

HANDLING THE CASTINGS

As previously mentioned, an overhead chain conveyor is normally used to transfer the castings to the fettling shop and allow them to cool on the way. The skips on this conveyor can be arranged for automatic discharge at either one or a number of points in the fettling shop, or can be arranged to pass a static grid on to which the castings can be raked and through which core sand, wires, etc. are allowed to fall before the casting is transferred to the various fettling operations. Steel slat conveyors, hand-pushed skips, or fork-lift trucks provided with suitable hopper attachments may be used for this latter function. Irregularly shaped castings can be handled by a mobile shop crane or a fork-lift truck equipped with a suitable crane attachment. Again, the castings may at this point be loaded into box pallets and handled by truck to the grinding station. An overhead runway, hoist block or skip hoist may be used for loading rumblers or sand blast units and these may be discharged into a hopper and then on to a slat conveyor to facilitate subsequent sorting. Floor-level slat conveyor or box pallets and fork-lift trucks may be used for transferring the fettled castings to the next department.

FUME AND DUST EXTRACTION

When designing a fully mechanized scheme it is important to bear in mind the question of fume and dust extraction, in order that this plant may be suitably located in the general layout. The main points at which this problem must be considered are at the pouring point, the knock-out and knock-out belt, screens, bucket elevators, chipping or fettling benches,

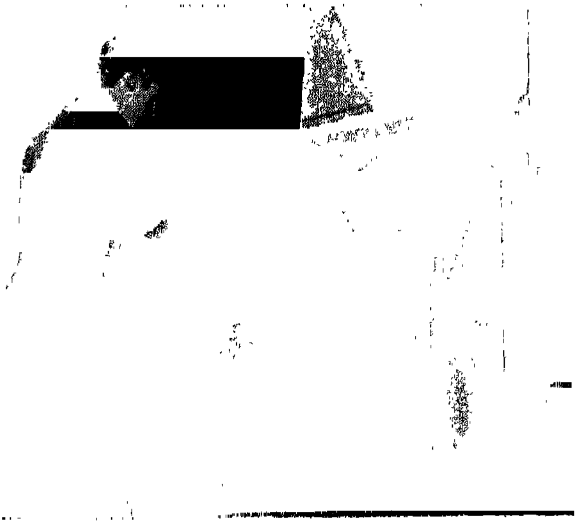


FIG. 13.11. *Two-station knock-out grid showing fume-extraction grilles.*

and grinders. Various methods of extraction at the pouring point are in use but where a continuous powered mould conveyor is used, it is usual to provide a continuous extract hood on the far side of the mould conveyor opposite the ladle. The velocity of the air being extracted through the grilles is calculated to ensure that all fumes are drawn into the extract duct. Under these conditions it is usual to inject fresh air into the foundry at this point, the duct being situated over the extract duct and directed down towards the pourers, providing a curtain of air within which fumes are trapped and avoiding draughts produced by the constant extraction of air from the building.

At the knock-out a similar system may be used provided it is possible to gain access to the top of the grid itself after placing the ducting and hoods in position (Fig. 13.11). If this is not possible, then an extract may be arranged immediately below the grid, although this has the disadvantages that a great deal of sand may be extracted and the extract headers may be blanked from the fumes by the knocked-out sand. Collection and disposal of the dust carried away from these extract points may be done in a number of ways, the simplest, of course, being the cyclone.

CONCLUSION

The successful running of a mechanized foundry plant depends on thorough and regular maintenance to ensure that the plant is kept in operation and that stoppages due to breakdowns are kept to a minimum. It also depends on all the operatives working together as a team, and many bonus systems have therefore been devised to encourage production. The need for regular and systematic inspection of all moving parts and regular oiling and greasing cannot be too strongly stressed since machinery in a foundry is constantly exposed to abrasion of the worst kind.

Appendix 1

INSPECTION OF CASTINGS

PRODUCTION methods must be supervised and castings checked in each stage of manufacture. The finished casting, before being released from the foundry, must be approved and passed as meeting the requirements of the customer's drawing and specification. Firstly, the casting must be sound and free from any surface defects. Metal thicknesses must be maintained in order that after machining the casting will meet dimensional requirements.

The various methods of testing castings are as follows:

(1) *Visual Inspection.* This comprises checking of thicknesses by the use of calipers, gauges, templates and so on. Visual examination picks out such faults as are evident without any special technique being employed. Special calipers may have to be designed to measure internal thicknesses.

(2) *Pressure Test of Casting.* Whole castings which are to be used to withstand pressures are tested in the foundry by various means. These vary according to the type of alloy and metal being used. The pressure test may consist in the application of air at a specified pressure inside the casting, and the whole submerged in water at a given temperature. Any leaks through the casting become apparent by bubbles of air being released through the faulty portions. An alternative method is to fill the cavities of a casting with paraffin at a specified pressure. Paraffin, having a very searching effect for the slightest porosity, will rapidly find any such defect and show quickly as an oily or moist patch at the position of the fault.

(3) *Radiology.* Tremendous advances have been made in the examination of all types of castings as a result of what is known as the X-ray examination. (See Figs. A.1 and A.2.) One method involves taking X-ray photographs, known as radiography, while another involves the screening of the castings, known as fluoroscopy. Modern X-ray photography is used generally for the heavier-sectioned castings and, although somewhat less rapid, it has the advantage that records of specimens can be kept and compared with those of other similar specimens produced at later dates. The use of the X-ray screening process is very much in vogue for small light-sectioned castings. It has the advantage of being able to examine a specimen immediately, without having to wait for the photographic process. The reason for rapid development of X-ray testing of castings is readily appreciated when the full usefulness of the apparatus is understood.

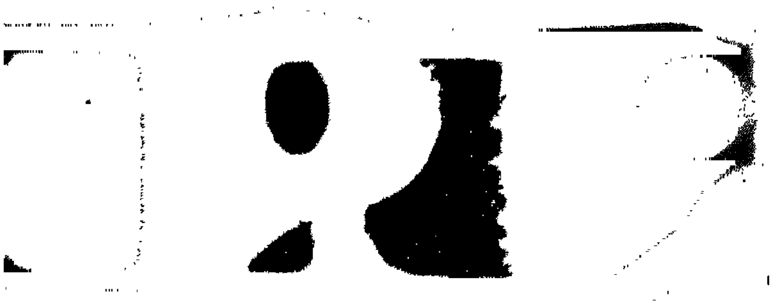


FIG. A.1. *X-ray photograph showing the appearance of a perfect casting.*

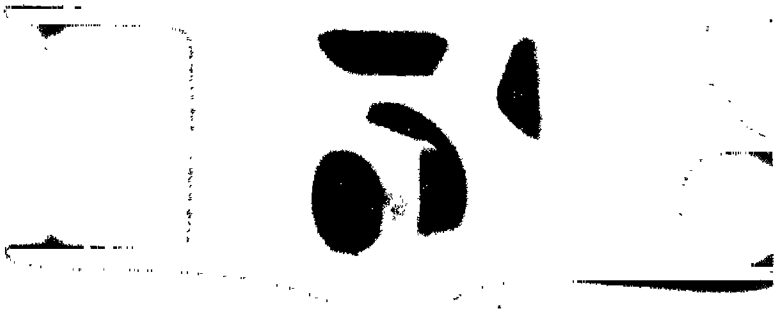


FIG. A.2. *X-ray photograph showing the appearance of an imperfect casting.*

With the use of X-rays, reproducing either photographically or by the medium of screening the complete structure of any section of the casting, it will be understood that defects which otherwise could not be detected become quite apparent. With the light alloys and steel castings, uneven sections which adjoin are prone to cause internal cavities. These cavities, although usually small, detract from the strength of the finished product. Apart from the X-ray method there are only two other alternatives for testing for this fault. Firstly, a certain percentage of castings from each batch are selected and cut open at the suspected point of defect. Secondly, on certain types of castings it is possible to arrange for a tensile or shear test to be made. As will be appreciated, both of these methods are costly and far from satisfactory. The use of X-ray examination has proved of paramount importance with the ever-increasing demand for a greater power-to-weight ratio, resulting in designers of engines, plant and machine tools having to rely on the founder to produce 100 per cent sound castings. This is especially the case in light alloy foundries.

(4) *Chalk Testing.* A further method of examination of castings is by that which is known as "chalk testing." This comprises castings being immersed in hot paraffin for a period of 1½ hours. The paraffin is cleaned from the surface of the casting, which is then dipped in clean powdered chalk. The paraffin which has penetrated into any cracks or defects in the casting is immediately drawn out, and it is very easy to distinguish where the chalk has adhered to the casting. The results of porous sections are shown by the chalk absorbing paraffin and appearing in a moist and discoloured state. Cracks in castings may be detected in this fashion. This type of testing applies to all branches of the industry, and particularly to light alloy die-castings.

(5) *Weight or Displacement Testing.* In many cases intricately-cored castings are extremely difficult to measure accurately, particularly the internal sections. It is important for three main reasons to ensure that these sections are correct in thickness: (1) there should be no additional weight which would make the finished product heavier than permissible; (2) sections must not be thinner than designed in case of detracting from the strength of the casting; (3) if hollow cavities have been reduced in area by increasing the metal thickness of the sections any flow of liquid or gases intended by the designer is reduced. A ready means of testing for these discrepancies is by accurately weighing each casting or by measuring the displacement caused by immersing the casting in a suitably filled measuring jar or vessel. In certain instances where extreme accuracy is demanded from the founder, a tolerance of plus or minus 1 per cent of a given weight only is allowed.

The above remarks apply in general throughout the casting industry. Specific castings calling for highly stressed metal are examined by methods peculiar to that particular type of casting.

Appendix 2

FOUNDRYWORK TRAINING AND RESEARCH

The foundry industry offers opportunities to all types of young men for training as craftsmen and executives in positions demanding skill and technical ability of a very high order. The industry requires engineers, metallurgists, chemists and other scientific workers, in addition to patternmakers, moulders and coremakers, furnacemen, inspectors and fettlers. The chances of promotion are possibly better than in any other industry and many training schemes designed to suit the various grades are available. Most of the training schemes are concerned with the training of craftsmen, and apprentices are employed by the majority of foundries in Britain. These apprenticeships extend over a period of five years, usually commencing at the age of sixteen. Practical experience is obtained on all of the classes of work manufactured by the firms concerned and often the apprentice spends periods in ancillary departments, such as the patternshop, laboratory, and drawing office. Many foundries take advantage of the facilities offered by the National Foundry Craft Training Centre, c/o Rudge, Littley Co. Ltd., West Bromwich, Staffs., and send their apprentices to the courses they provide. The technical training of the apprentice is catered for by many technical colleges, although a few firms have their own schools. The practical training he receives, coupled with the technical training acquired by part-time study, will enable the young man to hold his own with any craftsman in the world and may, provided he possesses the right temperament, enable him to gain promotion.

Young men who have received their general education in grammar schools and who have reached the standard of the General Certificate of Education (ordinary level), or have obtained an equivalent qualification, may enter one of the training schemes for foundry executives. Several schemes are available; a typical one is a sandwich course extending over a period of four or five years, consisting of about five months' full-time study in the local technical college each year, the remainder of the time being spent in the foundry and ancillary departments gaining practical experience. Schemes are also available to enable university graduates in metallurgy or engineering to enter the foundry industry. Many of the larger firms will arrange for practical training and experience over a period of two or more years to enable suitable graduates to qualify for executive positions.

FOUNDRYWORK TRAINING AND RESEARCH

Foundry technical training is available in many of the technical colleges throughout the country. The majority of the courses lead to the City and Guilds of London Institute examinations in foundry practice and patternmaking. These courses are designed for craftsmen and help the ambitious young man toward promotion. They extend over a period of four years and attendance at the local technical college is required either on three evenings per week or on one full day and one evening. Many foundries allow their apprentices to attend the part-time day courses. Successful students are awarded the intermediate certificate at the end of their second year and the final certificate after four years' study. The certificate of the City and Guilds of London Institute awarded to a candidate successful in the final examination (foundry practice or patternmaking) is countersigned on behalf of the Institute of British Foundrymen by the President of that Institute and is nationally recognized. Young men who obtain qualifications in metallurgy or engineering through Higher National Certificate courses can obtain an endorsement in foundry work. Those studying metallurgy for the Institution of Metallurgists examinations can take foundry practice as a subject in the A.I.M. examination.

The most advanced training in foundry technology and management is given by the National Foundry College, Wolverhampton. The diploma course of this college is a full-time one extending over a period of two years, of which six months is spent in the industry. The National Foundry College Diploma which is awarded to students who successfully complete this course is recognized as the premier award available. Young men who have acquired a basic knowledge of chemistry and physics and who possess a Final City and Guilds Certificate in foundry practice or patternmaking, a Higher National Certificate in metallurgy, engineering or chemistry, or a university degree in appropriate subjects can obtain admission to the college provided that they have had adequate industrial experience. Many firms financially support their employees while in the college and other students obtain aid from their local education authority or from other institutions.

The Institute of British Foundrymen caters for the whole of the foundry industry. It covers all aspects of foundrywork and holds monthly meetings at its various branches at which papers confined to foundry subjects are presented. The annual conference is held in a different part of the country each year. When the International Foundry Congress is held in Britain the Institute of British Foundrymen acts as host. The Institute's activities include many aspects of foundry education and training, and various technical committees each dealing with a different problem of research or investigation on which young foundrymen are often invited to serve.

The industry is served by three national research associations, the

British Cast Iron Research Association, the British Steel Castings Research Association and the British Non-Ferrous Metals Research Association. Each concentrates on research and other services connected with its own branch of the industry. The B.N.-F.M.R.A. serves the whole of the non-ferrous industry and deals with both cast and wrought materials, whereas both the B.C.I.R.A. and the B.S.C.R.A. deal exclusively with castings and associated problems. All three associations give advice and actual help in solving the problems which arise daily in foundries.

Specialized libraries are available in many of the larger cities and the three research associations possess excellent libraries containing textbooks, journals of the various professional bodies, periodicals, extracts and foundry literature generally. A great service is also rendered, free of charge, by the bureaux of information organized by the major companies interested in the production and marketing of nickel, copper, aluminium, lead and zinc.

As with the research associations, the trade associations confine their activities to their own section of the industry. The Council of Iron Foundry Associations covers the whole of the cast-iron section of the industry including malleable cast iron. Its members comprise the various local iron-founding associations together with those associations which cater for specific types of iron castings. The activities of the C.F.A. are numerous and include training for the iron-foundry industry, a special committee having been formed to deal with this problem. The other three major trade associations, the Association of Bronze and Brass Founders, the Britis Steel Founders' Association and the Light Alloy Founders' Association similarly serve their respective branches of the industry. All are intereste in foundry training and education.

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